FRA TURES

AND

Drawings by MURIEL McLATCHIE MILLER

Photography by DONALD WITHEE

OTHER INJURIES

By the Members of the Fracture Clinic of the Massachusetts General Hospital and of the Faculty of the Harvard Medical School

Edited by EDWIN F CAVE, M D

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DEDICATED *to the "Spirit of Teaching" so loyally carried out over the years by the faculty of the Harvard Medical School and by members of the Massachusetts General Hospital Fracture Clinic—past, present, and future*

and let him who is instructed in the word
share all good things with his teacher.—Gal. 6:6

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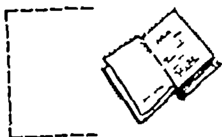
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Preface

IN 1938 the members of the Fracture Clinic of the Massachusetts General Hospital wrote a text on *Experience in the Management of Fractures and Dislocations* under the editorship of Dr Philip D Wilson This book had considerable merit in that it was the first volume of its sort in which the opinions of various authors were substantiated by end result studies Such studies had at that time been completed in the Clinic on more than 4 000 cases of fractures and dislocations The book was therefore unique among textbooks on fractures

When it was suggested some 5 years ago that a new text based on our experience as a group for more than 25 years be published from the Fracture Clinic we wondered whether there was actual need for an additional volume on fracture management. Since however the Clinic no longer confines its teaching efforts to treatment of fractures and dislocations but now includes treatment of all forms of trauma we believed that a publication dealing with all types of injury might be worth while Furthermore hundreds of postgraduate students who have taken the fracture course (Treatment of Fractures and Other Traumatic Conditions) at the ' setts General Hospital since it ' duced 30 years ago have on occasions requested that a volur lished covering the material pres ing their course of instruction I our privilege to have more than 1 graduate students from every st country and from ten foreign n therefore have a group of "alu tered throughout the world We to these men and women many have taken the course on more occasion and we trust that our teaching have to some extent sated for the time and expense for their stay in Boston during th their postgraduate instruction

The usual successful fractur is generally written by one autho tic terms with a definite recom for the management of a particu injury Every physician howeve that no one method should alwa to the exclu ion of others The p ume was written by a group of and surgeons from the staff of chusetts General Hospital and o vard Medical School most of w had many years of experience with the subjects about which written Various chapters called types of presentations Some

*Wilson P D (ed.): *Experience in the Management of Fractures and Dislocations* (based on an analysis of 4,390 cases by the staff of the Fracture Service of the Massachusetts General Hospital, Boston) (Philadelphia: J B Lippincott Company 1938)

1  History of the Fracture Clinic of the M G H.

THE FRACTURE CLINIC of the Massachusetts General Hospital was established in 1917 by Charles L. Scudder and was the first such clinic in the United States Dr Scudder was the first Chief of the Clinic and assigned with him were Henry C Marble George A. Leland Torr W Harmer and Richard H Miller from the East and West Surgical Services After World War I great impetus was given to the study of the treatment of fractures throughout the United States and in 1919 the Fracture Clinic began to function as a separate unit of the Surgical Services Postgraduate teaching of fracture treatment was initiated by Dr Scudder who was assisted by the above named general surgeons and by Robert B Osgood Chief of the Orthopaedic Service and Zabdiel B Adams and Philip D Wilson also from the Department of Orthopaedic Surgery

In 1920 Dr Scudder retired from hospital service and was succeeded as Chief of the Clinic by Daniel F Jones of the Surgical Service and in 1924 by Nathaniel Allison of the Orthopaedic Service as Associate Chief During the period of service of Drs Jones and Allison the Fracture Clinic reached its full stride in providing the best of care for patients suffering from injury and as a teaching service Although end result studies of fractures were begun largely at the instigation of Dr Osgood in 1919 the value of these studies was not evident until the late 1920s when (in 1928) sufficient knowledge of the treatment of fractures had accumulated to permit giving the first postgraduate course in the management of fractures and dislocations Dr Jones retired in 1929 and he was replaced as Chief by Henry Marble Dr Allison relinquished his duties at the Massachusetts General Hospital in 1930 he was succeeded by Philip D Wilson as Associate Chief George W Van Gorder was made Associate Chief when Dr Wilson moved to New York in 1934 Drs Marble and Van Gorder were replaced by Arthur W Allen as Chief and M N Smith Petersen as Associate Chief in 1940 They served until 1947 Edwin F Cave was Chief from 1947 to 1957 when the present Chief Otto E Aufranc was appointed

Before World War II fracture admissions to the wards were rotated in order to the East and West Surgical Services and the Orthopaedic Service Since 1947 all fractures other than those involving the skull have been admitted to the Orthopaedic Service unless there were major complicat

ing injuries involving the central nervous system abdomen or urologic organs in which case the patient has been admitted to the appropriate section and any frac tures associated with these injuries have been cared for by the fracture surgeons

plaster-of paris bandages were often of poor quality "Setting" of the plaster was always a problem and catalyzing agents (such as salt) were added to speed the process Pa tients with fractured hips were immobilized in large double spicas which soon became


CHARLES L. SCUDDER
1917–1920


DANIEL F JONES
1920–1929


NATHANIEL ALLISON
1924–1930


HENRY C MARBLE
1929–1940


PHILIP D WILSON
1930–1934


GEORGE W VAN GORDER
1934–1940

The Massachusetts General Hospital Fracture Clinic has experienced many changes in fracture management since its beginning in 1917 Then with few exceptions all fractures and dislocations were treated by manipulation and splinting Many of the splints were ill fitting and loose and did not provide stability to the fracture The result was a high mortality and for those patients who did survive there remained joint stiffness muscle weakness and often leg shortening—all of which contributed to permanent invalid ism Nevertheless we have as have most

fracture clinics continued to treat the vast majority of long bone fractures by traction or closed manipulation and external splinting This practice will of course continue but as surgical techniques in general have improved the operative management of fractures has developed and with considerable justification Some of these developments have occurred in our own Clinic The operative management of fractures had been advocated sporadically only to be abandoned for many generations but it was more firmly established early in the century by Sir Arbuthnot Lane of Guy s Hospital, London. Lane believed that the "no-touch technique" was a major factor in a successful open reduction. His chief difficulty however lay in the fact that the plates and screws he employed corroded in tissue caused reaction broke and frequently had to be removed Lane himself believed that when this occurred it was due to "dirty surgery"



ARTHUR W ALLEN
1940–1947



M. N SMITH PETERSEN
1940–1947

In America, fracture management continued along "conservative" lines until about 1915 when William O'Neill Sherman surgeon to the Carnegie Steel Company Pittsburgh accumulated a vast experience from openly reducing and securing with steel, long bone fractures particularly those of the femur Sherman was an able surgeon and a master of technique in applying plates and screws He was dexterous and quick and since he was dealing with relatively young persons (steelworkers) and since his operations were done soon after injury a high percentage of his patients did well were soon out of bed and returned to work at a relatively early date The quality of metal was however still a problem and as in the case of Lane many of the plates and screws advocated by Sherman and employed by others broke infection supervened and the metal had to be removed. Not infrequently osteomyelitis and nonunion of bone followed The no-touch technique was not the answer although it was continuously practiced in some clinics in the United States and abroad.

Some members of the present Massachusetts General Hospital Fracture Clinic will remember Sherman as rotund, ruddy complexioned and having a strong personality He spoke fluently and did not fail to state his opinion with force He dressed like a "Broadway actor" and was obviously fond of his food. It was always an exciting day when he visited Wards E and A at our Hospital, along with other fracture "greats" such as William E ("Bill") Darrach Bancroft Blake Cotton Gallie Estes Murray

and others in company with Drs Scudder Jones Allison Smith-Petersen Marble Wilson, and the other Clinic members These visits usually took place at the time of the combined meeting of the Philadelphia, New York, Brooklyn, and New England Fracture committees The meeting was always followed by a fine dinner where drink and food were not deficient and where as a result many lively arguments took place as to the best methods of fracture management

The establishment of the Fracture Committee of the American College of Surgeons in 1922 by Dr Scudder did much to improve the care of the injured patient throughout the country Other representatives on this committee from Massachusetts General Hospital have been Drs Allison Osgood Wilson Marble Leland Reggio and Cave

Regional subcommittees were established in various sections of the United States and Canada Representatives from these groups have done much to stimulate interest in the early care of the injured and the methods of transportation.

In 1949 the "Fracture Committee" of the College of Surgeons became the "Committee on Trauma " which emphasized the fact that when bone is broken there is always soft tissue damage of varying degree also that, owing to mechanized industry and the high speed automobile the patient with multiple injuries appears more and more frequently in the emergency ward Thoracic wounds and abdominal or pelvic wounds are often associated with injuries to the extremities

Since 1929 when Venable and Stuck brought out Vitallium to be followed a few years later by the standardization of steel manufacture open treatment of fractures has been more and more widely accepted

The thin flanged nail for femoral neck fractures conceived by Smith Petersen of the Massachusetts General Hospital Fracture Clinic in 1925 caused reaction in tissue in the early cases Some nails broke or extruded themselves as corrosion occurred around the nail Now however such an occurrence is rare and the Smith Petersen nail is still the best means of securing femoral neck fractures With improvement in metal construction has come also improved surgical technique Proper choice of a case for operation attention to the fact that soft tissues must be in good condition before they can be incised adequate carefully placed incisions gentleness in handling tissue sufficient but not unnecessary periosteal reflection careful reduction and firm fixation of the fracture careful wound closure without tension postoperative elevation of the extremity—all have contributed to the use of open treatment of fractures when necessary to restore normal anatomy and permit shorter hospitalization

Nevertheless the fundamental principles for promoting bone healing remain unchanged These principles we should never fail to teach Let us remember that open treatment of fractures is still high on the list of causes of nonunion of bone largely because of poor surgery The members of our Clinic strive to keep these thoughts uppermost in our minds and to preach what we practice

Medullarv nailing looked upon with disfavor when our wounded soldiers first returned from German prison camps after World War II carrying great long steel rods in their femurs is now an accepted form of treatment of long bone fractures Some will wonder why it was not thought of long ago It was tried by Nicolaysen in 1897 by Delbet in 1906 by Lambotte in 1909 by Hey Groves in 1916 and by others but it had to be abandoned because of poor quality of metal. Now medullary nailing is here to stay and many fracture surgeons believe it has been the greatest advance in fracture management since the Smith Petersen nail Our Clinic members have seen all of these new mechanical devices in their development We have tried many of them

Even more important, however has been our increase in knowledge as to the methods of handling the whole patient the management of the entire patient at the scene of the accident careful and simple splinting gentle and rapid transportation early evaluation of all possible injuries blood transfusion and judicious use of drugs to combat

possible infection The importance of skin coverage for any bone after injury did not become fully appreciated until World War II Now our Plastic Service is an extremely important part of the Fracture Clinic These advances and others have over the years been appreciated and tried by members of our Clinic We as a group may be regarded by some as too surgically minded and as "an operating clinic" However the fundamental ideas of patient care wound management and splinting of a fracture remain the same and we shall continue to keep them uppermost in our minds in caring for the injured and in teaching our students

The Fracture Clinic is indebted to many departments and many persons associated with the Hospital We think particularly of the section of Physical Medicine and Occupational Therapy headed by Dr Arthur Watkins and the Department of Social Service directed by Miss Helen Barbour

The Administration of the Hospital has provided funds for follow up studies which have laid the foundation for all of our knowledge gained from the observation of patients in the Out Patient Department, the wards and the Follow-up Clinic Every patient is allowed a visit and an x ray examination, without cost a year after injury

No instructor has ever been paid for teaching in the annual postgraduate fracture course The Clinic has borne its own operating expenses since 1928 deriving its funds from postgraduate teaching which have been sufficient to cover the cost of lantern slides and other necessary materials and to pay the salaries of the full time secretaries The secretaries have been Miss Mary E. Maloney who served from October 1924 to April 1948 followed by Mrs Jean Adams Blake from 1948 until March 1950 and the present incumbent Miss Marion G Melnick who succeeded Mrs Blake Michael E Morris the faithful orderly who has shown slides to hundreds of students will be remembered by the teaching staff and by the students as well

More significant however than any person or any particular activity of the Fracture Clinic has been the *esprit de corps* of the entire Fracture group throughout the years Our weekly "grand rounds" are always occasions for lively discussion and our twice yearly fracture dinners are traditional and are unique among teaching groups at Harvard Medical School There is something about fracture management that provokes argument though it be on the most friendly terms We hope that such will always be the case

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2 Organization of a Fracture Service

FRACTURES and related injuries are becom ing problems of increasing importance because of accidents associated with present-day rapid transportation and the expansion of heavy industry The treatment of such injuries requires trained personnel and special equipment. For these reasons many large general hospitals have found it expedient to establish a separate fracture service equipped to treat both ambulatory and hospitalized patients In order to fulfill this function the service must have

1 An accident floor where facilities are available for receiving the injured for eval uating the extent of the local trauma and the general condition of the patient, and for the treatment of shock.

2 A fracture ward for patients requir ing hospitalization.

3 An operating suite equipped with all the necessary instruments and apparatus for the open treatment of fractures

4 An out patient department, for the follow up care of all fracture patients

5 An x ray unit, in close proximity to the fracture ward accident room and out patient department clinic A portable x ray machine for use on the ward or in the oper ating room is a necessity

6 A plaster room and a splint r both readily accessible to the ward the dent room and the out patient departn

7 A fracture cart containing nece splints and other equipment for settir traction—essential for any fracture \

A prime requisite is adequate s Since bed frames often require outri for traction and containers are frequ needed for films of patients in trac space between beds is necessary For reason, patients should be kept in the wards Similarly in the accident roon out-patient department, space is esse because many patients are transporte wheelchair or litter or a portable x ra chine may be needed when a closed r tion is necessary

PERSONNEL

The professional staff of any fra service will vary according to the cir stances However experience has sl that the following are almost essenti the proper function of the service

1 The chief of the service should surgeon of broad experience in the ment of trauma particularly in the

NOTE In a special edition of the *Journal of the American Medical Association*, February 15 entitled A Guide to the Evaluation of Permanent Impairment of the Extremities and Back th tem for joint measurement recommended is in principle similar to that outlined in this chapte the neutral point is zero

FRACTURE RECORD

MASSACHUSETTS GENERAL HOSPITAL

Name Unit Age

Address Sex

Date of Entry Date of Discharge

Mechanism of Injury (when, where, how)

End Result

Year	F	F	A

Treatment prior to Entry

Fracture (or Dislocation)

Bone

Type			
	Closed	Transverse	Complications
	Open	Oblique	Epiphysial Injury
	Comminuted	Spiral	Nerve Injury
	Impacted	Greenstick	Blood Vessels

Examination (description of deformity, injury to soft parts)

Initial X-ray Report

TREATMENT

Anesthetic Used

Reduction

Closed

Open:

Fig. 1

operative and operative management of bone and joint injuries. In his capacity as administrator and adviser he can do much to maintain and improve the standards of treatment on the service. In this capacity too he can stimulate his associates to investigate the many problems in fracture treatment which still remain unsolved.

2. In addition to the chief, there should be surgeons from the departments of orthopaedic surgery and general surgery who are concerned with the routine fracture treatment in the hospital, in the out-patient department, and in the accident room. However, because fractures are often associated with trauma to other tissues, the

fracture service should include surgeons from the plastic service the departments of urology and neurosurgery and the dental service.

3 On the wards in the accident room and in the out patient department, much of the treatment will be carried out by the house staff In the larger hospitals this staff should consist of a fracture resident and as many assistant residents as are required to provide adequate care for the patients The ward and out patient department must, of course have a regular staff but of equal importance is the emergency ward In order that the seriously injured patients may receive the necessary immediate and often lifesaving treatment a qualified surgeon should be on duty and readily available at all times

4 The nursing staff is of particular importance It should include a head nurse who has been trained in the management of fractures particularly in the use of traction and splinting This type of nursing requires not only training but experience The importance of good nursing care in the prevention of serious complications cannot be overemphasized

Similarly trained nurses will usually be required in the out patient department and even on the accident floor in hospitals where large numbers of injuries are treated on an ambulatory basis

5 Ancillary personnel should include at least one orderly who has been trained in the use of plaster and traction. Such an orderly is essential for the maintenance and smooth functioning of the plaster room and fracture cart

6 A fracture clinic secretary will prove invaluable both for maintaining patients records and for arranging follow up visits or carrying out whatever clinical studies are undertaken by the service

7 A department of physical medicine will play a vital part in restoring function to the injured part and to the patient as a whole (see Chapter 44 on Physical Medicine and Rehabilitation) The best physical therapy however is that which the patient can give himself by carrying out active exercises. Heat and massage are of help but muscle power and joint mobility can only be restored by the active use of the muscles themselves

8 Occupational therapy during the prolonged convalescent stage of many injuries is a valuable adjunct to treatment The surgeon who sees his patient for only a few minutes daily often fails to realize the boredom associated with the many hours of physical and mental inactivity of a patient confined to bed. Reading television and the radio are a comfort to some but these diversions hardly give the satisfaction provided by manual training Such occupational therapy is particularly helpful when the patient can get about in a wheel chair or on crutches

9 No large hospital can function effectively without a department of social service and in no division of surgery are social workers of more value than on a fracture service when hospital stay and convalescence may be prolonged

MEETINGS OF THE FRACTURE SERVICE

Weekly meetings of the fracture service are desirable for the purpose of discussion and review of the fractures treated during the previous week. Both ambulatory and hospitalized patients should be considered A careful review of the x ray films and an inspection of traction and other apparatus will prove stimulating and instructive to all concerned as well as assuring the best possible treatment. In addition at these weekly meetings the end results of fractures treated in the past can be reviewed and discussed with great benefit to all those participating

FOLLOW UP CARE

Careful supervision of all fracture patients is essential until solid bone union has been attained and function has been restored to as near normal as possible Frequent return visits to the out patient department for inspection of splints or plas-

FRACTURE CLINIC

MASSACHUSETTS GENERAL HOSPITAL

END-RESULT RATINGS

All cases shall be rated at the end of 1 year from the time of injury except for patients who have been treated primarily elsewhere and who come for reconstruction surgery —arthroplasty arthrodesis osteotomy etc

Amputations shall not be rated in the routine A, F E *manner*

The end results of certain cases cannot be established at the end of 1 year (e g epi physial injuries) these cases must be followed for a longer period of time and rated at such time as the Fracture Clinic sees fit

The *Percentage Rating* shall be as follows

Rating	*0*	*from*	*0%*	*to*	*12½%*
"	1	"	12½%	"	37½%
"	2,	"	37½%	"	62½%
"	3	"	62½%	"	87½%
"	4	"	87½%	"	100%

The letters A, F and E are used to signify anatomical functional, and economic result

Anatomic Rating

There are four factors which make up the total of an *anatomical* result

1 Length
2. Alignment
3 Apposition
4 Angulation

The anatomical rating shall be based primarily on the roentgenogram—except for length

Functional Rating

There are four factors which make up the total of a *functional* result

1 Total functional result—subjective (asking the patient)
2. " " " —objective (by observation) muscle strength, and staying power
3 Joint movement above the fracture, as compared to the other side
4 " " below " " " " " " " "

Functional rating shall apply to function of the part as a whole with due evaluation *of function of adjacent joints*

Economic Rating

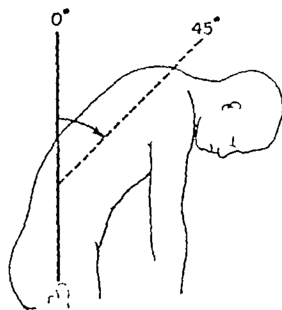
There are four factors which make up the total of an economic rating

1 Same work as before lighter or heavier work
2. " pay as before more or less
3 " hours of work " " "
4 " volume of work, " " "

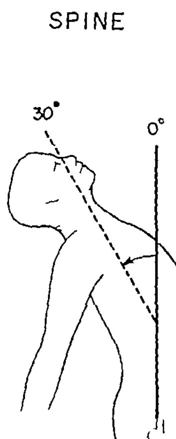
The economic rating shall be *measured not only* by the wage-earning capacity but also by the impairment of the person s general activities In the case of a housewife or of an elderly person neither of whom was earning money before injury any limita tion of the person s activity subsequent to the fracture must be estimated in the economic rating

Fig 2.

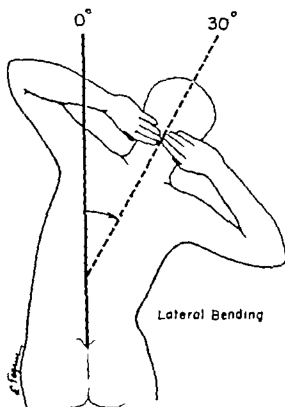
SPINE



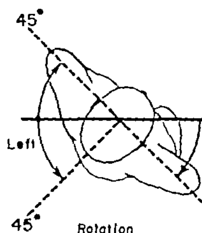
Forward Bending (Flexion)



Extension



Lateral Bending



Rotation

Fig 3 —Motion of spine (The *neutral position* cannot be defined) *Forward b* motion cannot be measured accurately in degrees but should be compared with normal for the age of the patient It should be noted whether the lumbar spine f verses itself Motions should be carried out in both sitting and standing positions It should be noted to what degree the dorsal and lumbar curves change *Lateral be* and left *Rotation* with pelvis fixed—right and left comparing angle made by t with pelvis

ter casings and for x ray films to check the maintenance of position are necessary

However in addition to this the follow up of fractures should include the end result study Where feasible all fracture patients should be evaluated at the end of the year At that time they should be questioned as to their present condition with particular reference to the function of the

many years (Fig 2) has proved quite satisfactory It may be summarized as follows

All cases are rated at the end of 1 year from the time of injury except where reconstructive procedures (e g arthroplasty arthrodesis or osteotomy) were required or where amputation had been performed Only patients treated primarily on the fracture service are included For some

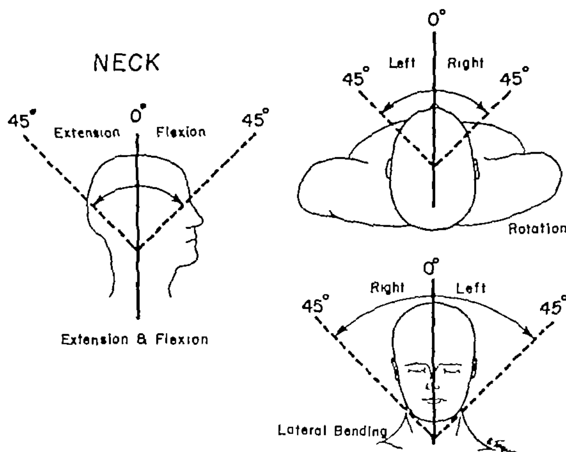


Fig 4 —Motion of neck. *Neutral position*—head up and chin in. *Extension* and *flexion* *Rotation*—right and left *Lateral bending*—right and left. All motions are recorded in degrees measured from the neutral point.

parts involved and to their ability to work. Finally a careful examination and x ray films of the involved part will furnish a complete record of the results of treatment and provide valuable data for future study

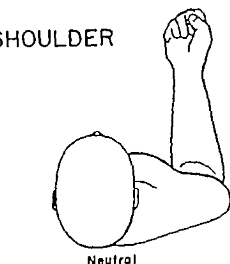
END-RESULT RATING

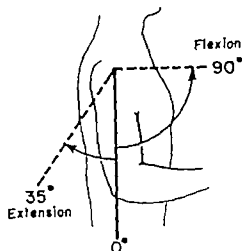
Fractures lend themselves well to follow up studies because they can be rated from the anatomical functional and economic viewpoints A system of rating employed at the Massachusetts General Hospital for

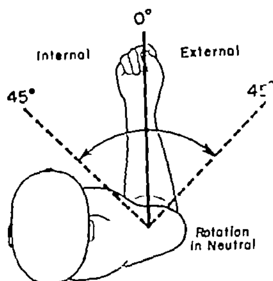
fractures an end result is not reached in 1 year additional visits at yearly intervals may be necessary for such conditions as epiphysial injuries and fractures of the femoral neck

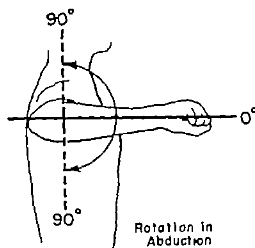
All fractures are rated on the basis of the anatomical functional, and economic results Each of these categories receives a numerical rating from 0 to 4 These numerals represent a certain percentage of recovery or restoration as follows zero (0) indicates 0–12½ per cent 1 12½–37½ per cent 2 37½–62½ per cent 3 62½–

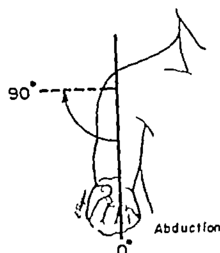
SHOULDER











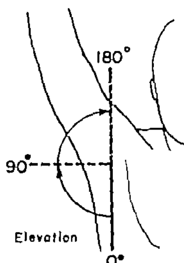


Fig 5 — *Motion of shoulder Neutral position*—arm to side elbow flexed to 90 degrees fore-arm pointing forward *Extension and flexion*—are measured with arm at side and with elbow flexed to 90 degrees *Rotation in neutral* To test for extreme internal rotation in neutral position arm should be placed behind back and compared with same motion with opposite arm. *Rotation in abduction*—carried out with arm abducted to an angle of 90 degrees with the side *Abduction*—maximum 90 degrees (Elevation is shoulder-girdle motion as compared with extension flexion rotation and abduction which are true humeroscapular motions)

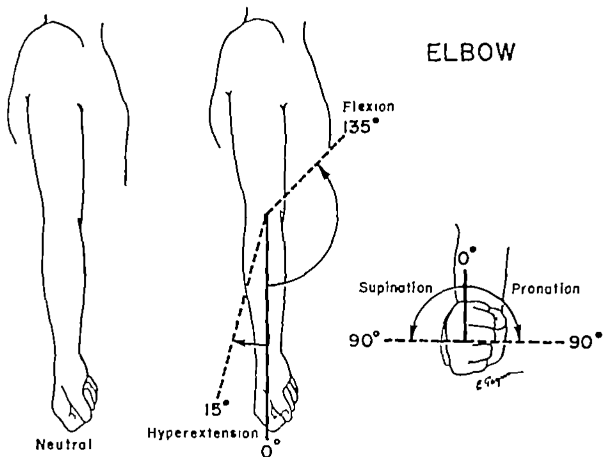


Fig 6 —Motion of elbow *Neutral position*—forearm in extension *Flexion*—measured from complete extension the neutral point. *Hyperextension*—measured in degrees as compared with the opposite elbow *Supination* and *pronation*—neutral point is midposition Elbow must be fixed at side in 90 degrees of flexion

When there is loss of complete extension this loss should be recorded in degrees of fixed flexion

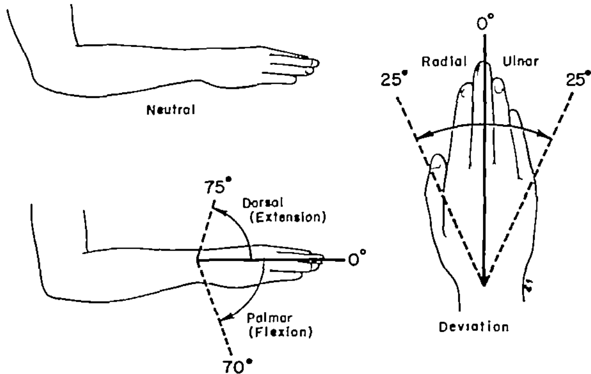


Fig 7 —Motion of wrist *Neutral position*—hand in line with forearm, with palm down *Dorsiflexion* (extension) *Palmar flexion* *Ulnar deviation* *Radial deviation* *Pronation* and *supination* as described under elbow (Fig 6)

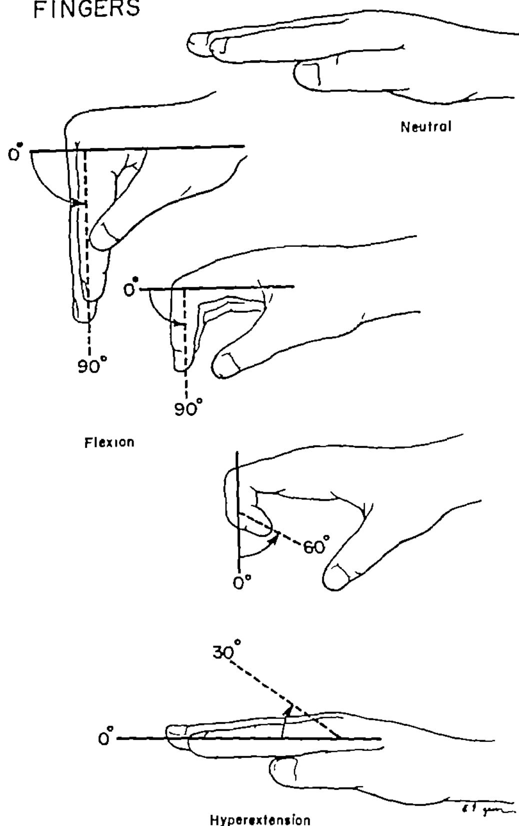


Fig 8 —Motion of fingers *Neutral position*—fingers in extension *Flexion*—all motions are in flexion either in the metacarpophalangeal or interphalangeal joints *Hyperextension*—should be noted if present. Test should be made for increased lateral mobility

87½ per cent and 4 87½–100 per cent The letters A F and E are used to signify "anatomical," "functional," and "economic" respectively Accordingly a perfect result would be indicated as A_4 F_4 and E_4 whereas a complete failure would be A_0 F_0 and E_0

ANATOMICAL RATING

The anatomical rating is based primarily on the roentgenograms taken at the time of the end result visit. The factors determining the anatomical result are union length alignment, and apposition Nonunion is of course rated as A_0 When a part such as the radial head has been excised the anatomical rating is zero (0) If union has occurred the anatomical result is estimated as the percentage of perfect restoration and is given the appropriate numeral. If more than one bone is involved each is given a separate rating

FUNCTIONAL RATING

The functional result is determined on the basis of (1) the patient s total function and (2) the function of the part involved in the injury The former must be determined by questioning the patient regarding his ability to do things as compared to his ability before the injury also by examining his muscle power endurance gait and posture etc The function of the part itself of course is determined by careful examination of all of the joints of the extremity both above and below the fracture site Such symptoms as pain weakness or stiffness must be taken into consideration in determining the numerical rating of function Similarly the condition of the patient prior to the injury will influence the rating. If there was pre-existing disability this should be taken into consideration for the functional rating of the final result should, of course represent a comparison with the patient s condition previous to injury

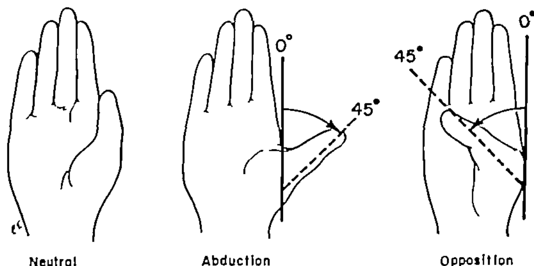


Fig 9 —Motion of thumb *Neutral position*—thumb alongside the forefinger and extended *Abduction*—measured by the angle that the thumb makes with the forefinger *Opposition*—cannot be measured in degrees but it should be noted how far the thumb comes across the palm. *Flexion*—measured the same as for the fingers (Fig. 8)

ECONOMIC RATING

In this category the patient s ability to earn his living now as compared to before injury is determined The following should be considered (1) the type of work—that is whether it is the same lighter or heavier

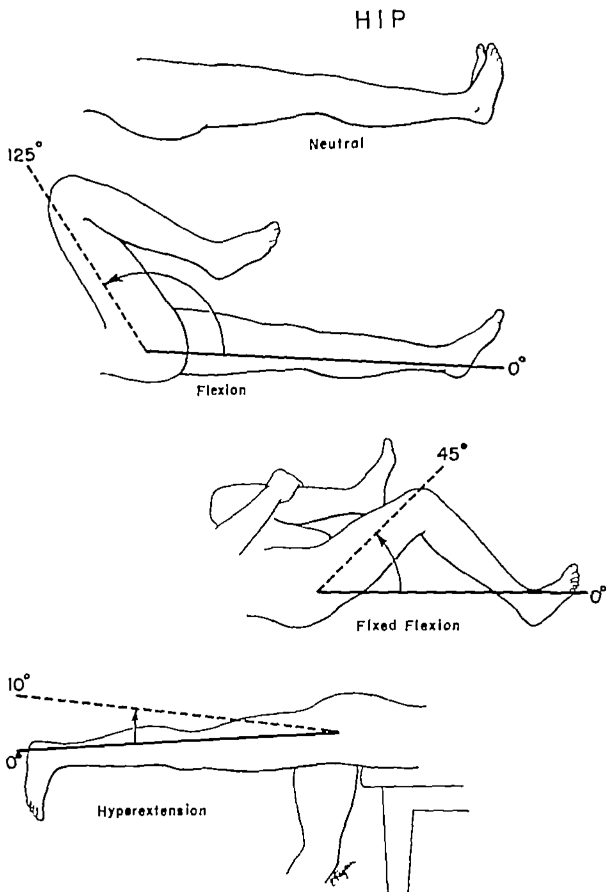
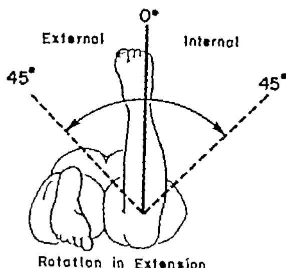
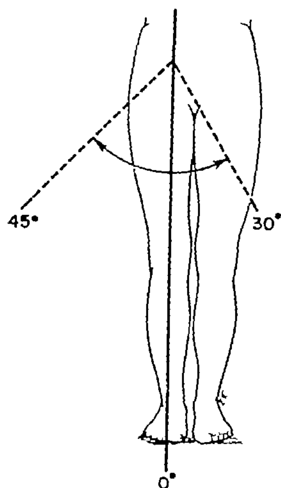


Fig 10 —Motion of hip *Neutral position*—hip in extension patella pointing upward *Flexion* measured with the knee bent opposite thigh must remain in neutral *Fixed flexion*—opposite thigh must be flexed in order to flatten the lumbar spine and to fix the pelvis *Hyperextension* —with patient lying prone with opposite thigh over end of table at an angle of 90 degrees ***(continued)***





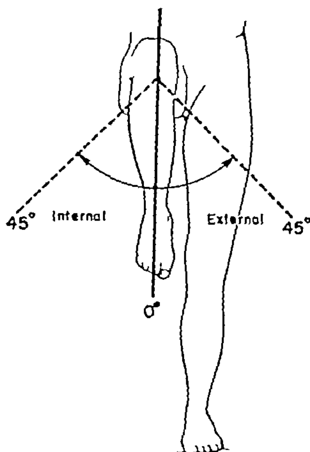


Fig 10 (cont.) —*Rotation* (external and internal) *in extension*—measurement should be made with patient prone and knee flexed to 90 degrees *Abduction and adduction*—measured from a line which forms an angle of 90 degrees with a line joining the anterosuperior spines *Rotation* (external and internal) *in flexion*—measurement should be made with patient on back with knee and thigh flexed to 90 degrees

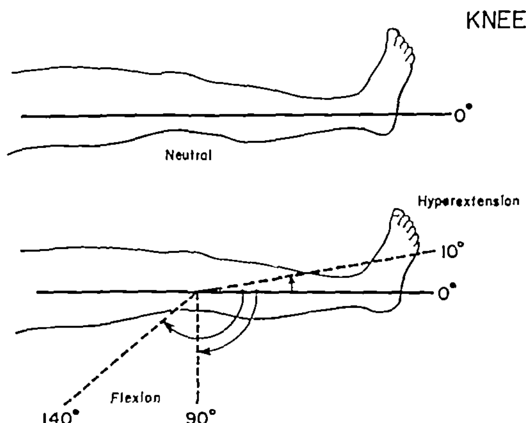


Fig 11 —Motion of knee *Neutral position*—complete extension of leg *Flexion*—measured in degrees from complete extension *Hyperextension*—measured in degrees from complete extension *Anteroposterior stability*—should be tested with the knee in 90 degrees of flexion *Lateral stability*—should be tested with the knee in complete extension When there is loss of *complete extension* this should be recorded in degrees of fixed flexion

than it was prior to injury (2) the amount of time the patient is able to work as well as the amount of work he can do and (3) the salary—whether it is the same more or less than it was before the fracture In some instances the economic rating must be based on factors other than wage-earning capacity For example a housewife s economic rating must be determined on her ability to do her housework, without reference to wage earning Similarly an elderly person who is retired or on a pension may present some difficulties in the assignment of an economic rating.

Obviously end result studies to be of value must be carried out with considerable care and the findings must be recorded in sufficient detail to permit study and comparison of various forms of treatment when the cases are reviewed in the future The lengths of extremities muscle atrophy and ranges of joint motion should be measured by means of a tape and a goniometer and carefully recorded Roentgenograms of good quality must be obtained in the anteroposterior the lateral and when indicated the oblique projections For comparison films of the opposite extremity will prove most valuable in some cases as for example in growing children with epiphysial injuries or other growth disturbances

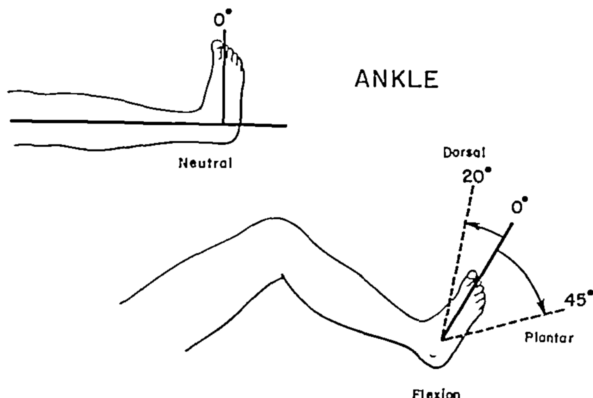


Fig 12.—Motion of ankle *Neutral position*—outer border of the foot at 90 degrees with the leg and in neutral as regards inversion and eversion. *Dorsiflexion*—should be tested with the foot in inversion measurements should be compared with knee flexed and with knee in extension to rule out tight calf muscles *Plantar flexion*—should be measured in degrees from neutral position

MEASUREMENT AND RECORDING OF JOINT MOTION

There is much confusion in the literature resulting from the different methods employed for measuring and recording joint motion A system employed at the Massachusetts General Hospital for many years and described by Cave and Roberts in 1936 has proved satisfactory It is now used by many clinics and has been adopted by the American College of Surgeons as the system



3 Metabolic Response to Trauma

HISTORY OF THE RESPONSE

TRAUMA OF any sort initiates a succession of physiological changes known as the "metabolic response" Both the nervous and endocrine systems are involved When the trauma is major such as a fracture of the femur or pelvis or an extensive burn, the metabolic response is clearly revealed in the clinical course of the patient. A lesser response has also been found to follow minor trauma an abdominal operation or even blood letting but in these cases clinical signs of the response are often absent

Cuthbertson a physiologically minded surgeon of Glasgow was first to recognize the metabolic response to trauma In 1936 he described the losses of nitrogen sodium sulfur phosphorus and potassium from the traumatized rat and a year later from the human being following fracture of a long bone In collaboration with Frank Young the English biochemist, he was also first to explore the possible endocrine origin of those losses Soon thereafter J S L Browne and Hans Selye of McGill University were exploring the nature of the response and its consequence both clinically and experimentally Browne described the loss of nitrogen through the kidney following a severe burn (1942) Selye studying the adaptive responses of rats coined the descriptive terms "alarm reaction" and "reaction of adaptation." Many other investigators had been interested in various detailed aspects of the body's response to trauma including that of the adrenal cortex (to be summarized later) but it was these workers of the British Commonwealth of Nations to whom we are indebted for the concept of metabolic response The results of these studies were available at the time the United States entered World War II

Immediately following the participation of the United States in the war a number of laboratories in this country joined the pursuit of this aspect of the metabolic response to trauma. Howard of Johns Hopkins University elaborated on the nutritional losses and their meaning in the therapy of patients following severe fractures He recognized the response particularly the loss of nitrogen as the normal sequel in the previously healthy individual and found that patients who had been ill immediately before trauma failed to show the response At the Massachusetts General Hospital the Surgical Research and the Huntington Cancer Laboratories collaborated in a series of studies of burned patients The pattern of nitrogen loss was not always consistent as

Howard had found in his patients Potassium was not lost in equivalent amounts an ambiguity that remains unexplained Albright studying patients before and after operations found patterns of losses and gains of nitrogen and minerals equivalent in proportion to those found in normal muscle and bone He was able therefore to assign the losses or gains to anatomical sites (The investigations of a number of the other laboratories involved in similar work will be mentioned later) Although there is still much to be learned regarding the response considerable understanding has been reached This chapter deals with this understanding

NATURE OF THE RESPONSE

The metabolic response to trauma is a *sudden change in metabolism which follows on the heel of the trauma* The metabolisms of nitrogen the electrolytes the carbohydrates and probably many specific substances are involved in the reaction Although a general pattern is described the response is by no means always consistent in form, degree or duration. The general

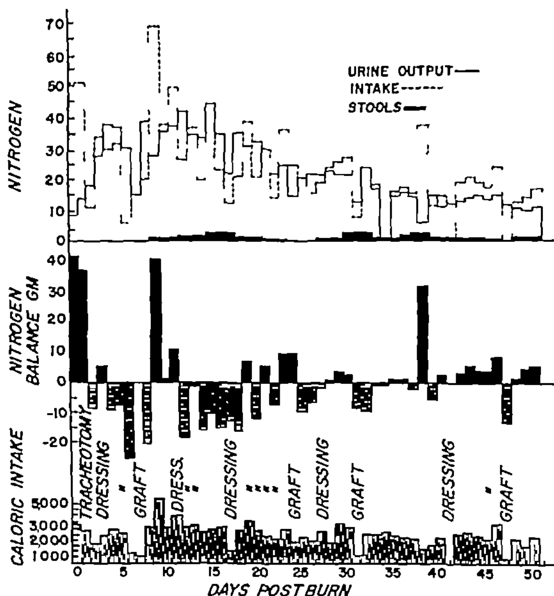


Fig 14 —Nitrogen balance of a previously healthy man aged 21 who suffered a 72 per cent total body burn 35 per cent full thickness The peaks of nitrogen are due to transfusions of plasma and whole blood

character and aberrations of the response are described initially by means of the nitrogen findings with the findings of the others following Nitrogen is selected for the initial part of the presentation because it is a basic constituent of tissue and has thus far been the most thoroughly studied which time the response has usually run its course The nitrogen balance of a severely burned patient is shown in Figure 14

The typical response with a prolonged negative nitrogen balance is encountered following any major trauma, including an open fracture of the femur or an extensive

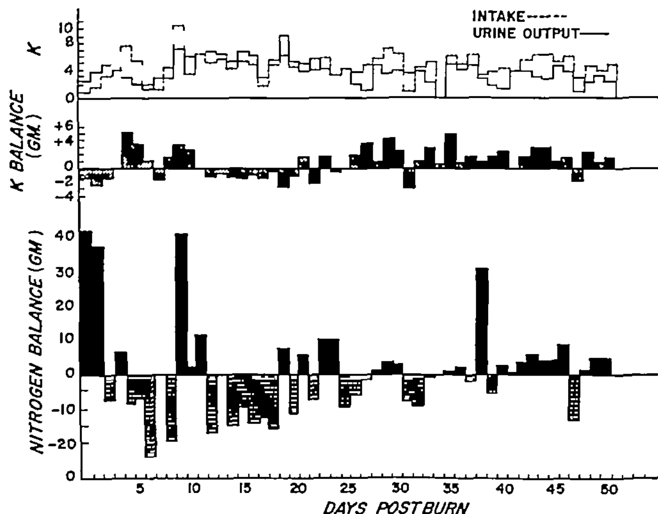


Fig 15 —Potassium balance of same patient whose nitrogen balance is shown in Figure 14 (Nitrogen balance from Figure 14 is repeated for ready comparison of the two balances)

Nitrogen

Immediately following an injury of almost any character there is an increased excretion of nitrogen through the kidneys If the injury has been severe and the patient previously healthy the amount of nitrogen excreted is large the patient passing promptly into negative nitrogen balance The amount excreted reaches a maximum within the first 2–7 days and the excess may continue for as long as 30–35 days by deep burn A lesser response follows a lesser injury A small increase in excretion follows any major operation and lasts for only 1–2 days This is a minimal response There are intermediate patterns between the minimal and the major response

The expected response fails to occur in an occasional patient following even a major trauma. This failure was first encountered by Howard following the fracture of a femur in a patient who had previously

been bedridden with arthritis The burn group found a similar lack of response at the Massachusetts General Hospital in a woman aged 30 bedridden with pulmonary tuberculosis at the time she was severely burned The failure of response in such patients is believed due in all probability to the patient s being in an unresponsive phase of chronic alarm The pulmonary tuberculosis had initiated the metabolic response some time previously

Electrolytes

The pattern of electrolyte excretion is also distorted in the response to trauma Details of the pattern are modified by the fluid therapy Without therapy following a fracture the patient excretes an increased amount of potassium for the first 2 or 3 days and at the same time retains sodium Later the patient returns to a normal balance of these electrolytes In the burned patient the therapeutic fluid contains a considerable amount of sodium and there is generally sodium retention for the first 2–3 days followed by a negative balance of sodium Potassium is excreted in excess for the first day or two and then potassium balance is resumed for the remainder of the acute illness and convalescence (See Figure 15 and Chapter 42 on Burns)

The independence of the pattern of the excretion of potassium to that of nitrogen is remarkable It indicates either that the nitrogen excreted in excess comes from a nontissue storehouse or if from cells that the cells can dispense with nitrogen without their actual breakdown. Otherwise potassium would have been liberated in an equivalent amount The chloride pattern generally follows the sodium pattern

The phosphorus balance is similar to that of the potassium. A slight negative calcium balance has been noted in patients following a major fracture but is not found in the burned patient It is presumed that the osteoporosis of disuse is the source of the excreted calcium

The balance of magnesium has only recently been measured in the burned patient and it has been found to follow a course independent of that of either nitrogen or potassium There is a significant magnesium loss particularly in the exudate

Investigators are not agreed as to the nature of the negative nitrogen balance Some hold that it is an obligatory loss and have observed that nitrogen injected intravenously is excreted quantitatively over and above that anticipated from the responsive cells Others principally William E. Abbott believe that the response represents an acute starvation and can be eliminated by the feeding of adequate calories Probably both points of view are to some extent correct the differences having arisen from measuring different situations Recently at the Massachusetts General Hospital a study was made of 25 patients with perforated ulcers and under this circumstance the negative nitrogen balance was found to be of minor degree and short duration The negativity can be eliminated by raising the intake something difficult to accomplish following a severe burn

Carbohydrates

A disturbance in carbohydrate metabolism (first described during World War I) follows various forms of trauma The blood sugar level is elevated and there is sometimes an excretion of sugar in the urine This disturbance lasts only for the first few hours It may be intensified by anesthesia. Its presence does not indicate diabetes mellitus and its degree may be influenced by intravenous therapy

Fat

The disappearance of the fat of the body following trauma probably represents a need for calories No specific need is known

Metabolic Rate

A rise in metabolic rate is characteristically found following certain traumas but

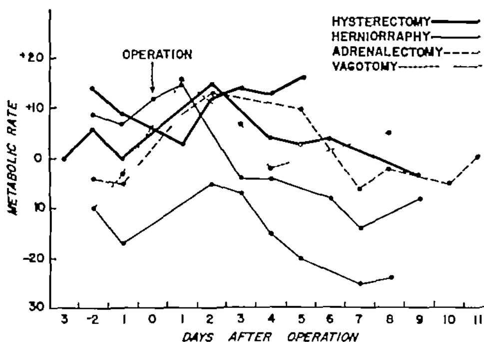


Fig 16 —Metabolic rates before and after operations

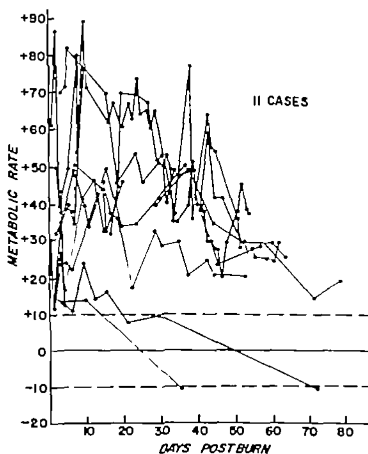


Fig 17 —Course of metabolic rate of 11 extensively burned patients in initial weeks after injury

not others After a major operation the basal metabolic rate does not exceed the normal range although there may be a slight increase over the preoperative level (Fig 16) No greater rise follows a major fracture Immediately after a burn in contrast the metabolic rate rises sharply falling slowly to normal as the wound heals

Vitamins

An increased utilization of vitamin C has been observed following a severe hemorrhage and severe trauma An increase in the utilization of other vitamins has been postulated but not documented A greater intake of all is presumably within therapy

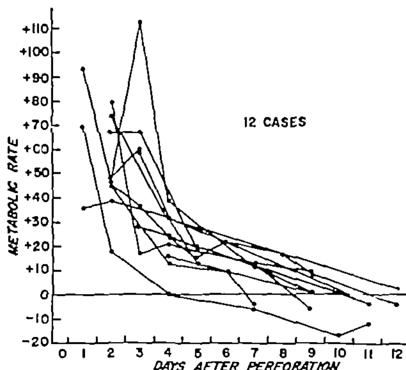


Fig 18 —Elevation of metabolic rate following ulcer perforation and operation (12 cases) All patients studied showed an abnormally high oxygen consumption in the first 3 days During the remainder of the first week the metabolic rates returned gradually to the normal range

(Fig 17) In extensively and deeply burned patients the metabolic rate in the first week or two after injury may assume the level of severe hyperparathyroidism and remain elevated for the weeks needed to graft the wounds Following an acute perforation of a peptic ulcer with operative closure the metabolic rate is similarly elevated during the first day but returns to normal by the fourth or fifth day after injury (Fig 18) The elevation noted in the severely burned patient presumably accounts in large measure for the wasting so frequently observed in these patients Although some of the rise in rate may be due to fever additional factors presumably chemical activity in the wound are in large part responsible

Red-Cell Formation

The new formation of red cells is sometimes slowed or stopped by severe injury Following a severe fracture or burn, the new red-cell formation measured by injected radioactive iron, may be decreased to 25 per cent of normal during the first 3 weeks after injury Later when the wound is healing the output of red cells slowly approaches normal This decrease in formation may be due not only to the trauma but also to the toxins of infection This is particularly true in the extensively burned patient In the infected patient there may also be continued red-cell destruction increasing the rapidity of the development of anemia

White Cell Changes

A rise in the white-cell count and a fall in the eosinophil count are characteristically seen following trauma. The duration of these changes depends on the nature of the trauma and the ensuing complications of this condition Following minor trauma, the return to normal is prompt After more severe injury the changes may continue indicating ominous complications In the burned patient a gradual rise in the eosinophil count to a high level indicates a healthy response and is related presumably to the immune response to the infection. A high tide of the eosinophils is paralleled by observable alteration in the wounds from edematous to compact healthy granulations

Thymus and Lymph Node Changes

The thymus gland and the lymph nodes shrink in response to trauma. This has been clearly demonstrated in experimental animals and is also believed to occur in human beings It has been most clearly observed in the child. It is also accompanied by a fall in the lymphocyte count in the blood. The meaning and progress of the lymphoid shrinkage has not been determined but it is believed to be related to the development of immune bodies and is a part of the defense of the body against threatening infection.

Genesis of the Response

The metabolic response to trauma is believed to be initiated by the nervous system with the actual metabolic derangement being due to the subsequent endocrine changes Action along the nervous pathways is currently postulated to occur in two ways. Pain activating the autonomic nervous system is probably the initiating stimulus The autonomic nervous system then arouses the endocrine glands either through the hypothalamus to the pituitary or through the adrenal medulla, with secretion of epinephrine and norepinephrine. The disclosure of the hypophysial portal circulation with blood coursing from the hypothalamus to the anterior pituitary gland has indicated that a humoral stimulator of neural origin in all probability passes from the cells in the hypothalamus via the circulation to stimulate increased anterior pituitary activity The anterior pituitary gland in turn controls the activities of the adrenal cortex, the gonads the thyroid and the pancreas

A neurosecretory association parallel to that of the hypothalamus and anterior pituitary is the nervous system stimulation of posterior pituitary function The posterior pituitary is connected by the neural stalk with the supraoptic nuclei Pain has been demonstrated by O'Connor and Verney to be accompanied by secretion of antidiuretic hormone and the mechanism being pain to the supraoptic nuclei to the gland At the present time the hormone is believed to be secreted in the hypothalamic nuclei and carried down the stalk to the posterior lobe from whence it is released into the blood stream There is evidence that antidiuretic hormone is released in the first hours and even days following severe injury

Pain also stimulates the secretion of epinephrine and norepinephrine from the adrenal medulla through the peripheral sympathetic nervous system The preganglionic fibers of the sympathetic trunk enter the adrenal medulla, where the secreting cells are ganglion-cell derivatives Vogt and Long and their co-workers have demonstrated that the release of epinephrine into the circulation is followed first by stimulation of the anterior pituitary to secrete ACTH (adrenocorticotropic hormone) which in turn increases the output of the adrenal cortical steroids

That this subsidiary method stimulates the adrenal cortex is still disputed Whether or not the secretion of epinephrine is responsible certainly the sympathetic division of the autonomic nervous system is immediately activated as part of the body's response to trauma and epinephrine secre-

tion is a sequel The blanching commonly seen following trauma is the visible sign of this sympathetic activity The nausea vomiting and sweating also common sequels are the counterbalancing reactions of the parasympathetic division

The nervous system reaction to trauma is an acute phenomenon probably of short duration It launches the slower moving more ponderous endocrine phenomena Once the endocrine forces are launched however they are apparently self perpetuating Little is known about the chronic phase of nervous system involvement although it is clearly possible that the pain from moving a fracture from doing a dressing and from repeated operative procedures may each in turn reinstigate the endocrine changes and revivify the metabolic response

The entire endocrine system is probably involved in the full blown response to trauma. Some glands are immediately stimulated—the adrenal medulla the anterior pituitary and the posterior pituitary mentioned above The adrenal cortex is secondarily stimulated to oversecrete The gonads and presumably the thyroid are in abeyance The pancreas may be transitorily stimulated to increase its output of insulin in the initial hours when hyperglycemia and glycosuria are present but this is unproved No change in parathyroid function has been demonstrated

An increased activity of the adrenal cortex is by and large the most significant response affecting intermediary metabolism There are many indications that trauma, mild to severe is followed by an outburst of the adrenal cortical steroids Following mild trauma, the outburst is slight and of short duration After severe trauma the outburst is approximately doubled and the duration of the increase extends well throughout the course of the illness If the illness is prolonged and severe the cortex of the adrenal gland undergoes hyperplasia The evidence for increased activity of the adrenal cortex is therefore threefold anatomical evidence in the adrenal itself the presence of metabolic reaction consistent with increased activity of the steroid hormones of the adrenal cortex and measurable increases of active adrenal steroids both in the blood and in the urine

In persons who have died within seconds following trauma such as in electrocution no changes from the normal anatomical pattern have been found in the adrenal cortex In patients who have died within a few hours following trauma the adrenal cortex has exhibited changes consistent with acute depletion of hormones In patients who have died 3–4 weeks following trauma (e g a severely burned patient with extensive infected wounds) evidence of considerable cortical hyperplasia has been found at autopsy

The metabolic changes described above are presumably due—in part at least—to an increased output of the various adrenocortical hormones The sodium and potassium excretion patterns are consistent with aldosterone excess The elevated blood sugar level and glycosuria, although also influenced by epinephrine are presumably related to the increased secretion of hydrocortisone The outpouring of nitrogen and the negative nitrogen balance are also consistent with excessive secretion of the hydrocortisone compounds Such secretion also accounts for the drop in eosinophils and the rise in blood pressure In severely burned women with open wounds of long duration growth of hair consistent with adrenogenital activity is common Occasionally such patients assume the rounded facies and develop the skin striae so characteristic of Cushing s disease

Following trauma an outpouring of adrenal steroids has been encountered in the urine The first of these to be disclosed was that of the 17 ketosteroids For the first weeks after severe trauma the amount excreted is double the anticipated normal In most patients particularly women, after the first week the excretion falls off to normal or subnormal and it remains at a low level until convalescence is well advanced (Fig 19) The 17-oxysteroids have also been found to increase The increase ap-

pears more slowly and persists longer than that of the 17 ketosteroids Very recently methods have been developed for the measurement of the adrenal hormones in the blood plasma and these hormones have been found at levels well above normal following various forms of trauma.

Gonadal activity typically is abated following severe trauma Apparently the body that is threatened by disaster can well dispense with gonadal function The energies normally needed for procreation can be turned elsewhere to advantage The cessation of gonadal function is presumably determined by a change in anterior pituitary function There may be no change in gonadal activity following minor trauma or if the activity is suppressed it may be of short duration Following severe trauma in both sexes however complete gonadal suppression is the rule The suppression in the female is judged by amenorrhea and a softening of the glandular tissue of the breasts In the male loss of gonadal activity is more difficult to judge Loss of erection the one sign is a more complicated phenomenon than amenorrhea in the female and it may have additional causes

The thyroid gland continues to secrete at an approximately normal level in most patients with trauma Increased activity of the thyroid has been ruled out as a cause of the increased metabolic rate seen following a perforated ulcer or a severe burn The rate may be slightly reduced in others A change is consistent with the increased activity of the adrenal cortex. A slightly lower activity is observed both in patients with Cushing s disease and in people without adrenal disease who have been injected with ACTH and given cortisone

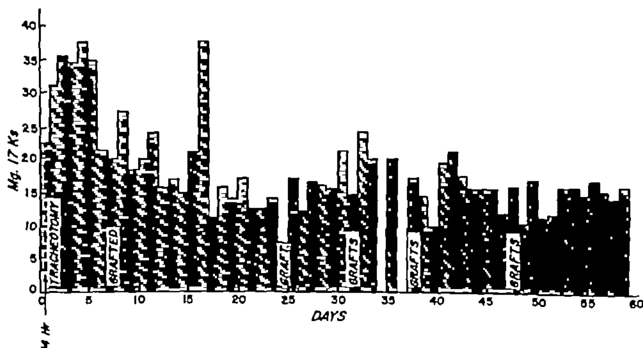


Fig 19 —Urinary excretion of 17 ketosteroids of the burned patient whose nitrogen and potassium balances are shown in Figures 14 and 15

TREATMENT

Treatment of the metabolic response to trauma is nutritional. In the absence of knowledge to the contrary the metabolic response is judged to be the normal reaction of the healthy individual and is therefore to be supported not altered Only when a specific insufficiency is known to have existed prior to the trauma is any specific therapy indicated Thus if a patient was known to have Addison s disease

before receiving the injury then part of the patient s treatment will be to supply the added amount of adrenal hormone needed over and above the maintenance dose Without such added hormone the patient makes a poor and perilous response The failure of the addisonian patient to react is another indication that an outburst of adrenal activity is part of the normal response to trauma

The therapy indicated specifically for the trauma itself is not included in these considerations But over and above the fluid therapy indicated for the burned patient for example the dietary intake should be supportive First of all the diet should contain if possible as many calories as the patient is burning The intake should not be pushed to the extent of causing nausea or upsetting the gastrointestinal tract It is better for the patient to lose weight than to develop vomiting or diarrhea The diet should also contain enough protein to maintain the nitrogen balance The entire diet need not be protein however since an adequate number of calories probably spares some nitrogen breakdown The diet may contain tolerable amounts of fat

If the gastrointestinal tract is not working then as much nourishment should be given intravenously as possible Human plasma and whole blood are the best sources of protein amino acids given intravenously spill out through the kidneys Since it is difficult to secure the full caloric requirement in the form of carbohydrates the new intravenous fat preparations are useful An enlarged intake of vitamins should probably be provided For severely burned patients 1 Gm of vitamin C is recommended daily

Particular attention should be paid to the development of anemia If anemia appears the patient is to be treated by transfusions up to the point of a low normal level The bone marrow will presumably be no further suppressed Iron and the B vitamins should be supplied

Hormone therapy for the previously healthy individual is almost certainly not indicated Testosterone has been recommended in the past because it promotes a positive nitrogen balance There is no evidence however that the retained nitrogen goes to the wound or into immune bodies It is almost certainly driven to the skeletal muscles where it is not needed by a patient at rest The nitrogen of these muscles has presumably been expendable for the defense of the body Theoretically therefore testosterone may be harmful

More recently ACTH and cortisone have been recommended Reasoning similarly in a previously healthy individual there is no indication that the body s own adrenal glands do not put out a sufficient amount of these hormones The main thing about adrenal therapy therefore is to maintain by transfusions an adequate circulation to the patient s own adrenal Then the proper amount of the hormone will be governed by the body s new set of priorities The giving of active hormones either in the form of adrenocortical hormones thyroid or sex hormones will only upset the newly established balance between the endocrine glands Until our wisdom approaches that of the body it is best to withhold such hormonal therapy tempting though it may seem at times in a disastrously ill patient

Psychological support of the patient is important This is particularly true in the severely burned patient Suddenly rendered helpless he may be upset by the total dependence on others for feeding moving his bowels and urinating He becomes irritable and primitive in speech and behavior He needs support psychologically if he is to have a reasonable fluid and dietary intake Appetite in the sick patient is precarious at best and improvement in psychological reaction may be of enormous help in the maintenance of his nutrition

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4  Healing of Fractures

THE HEALING of fractures is determined to a large extent by three principal factors the quality of the reduction the degree of fixation by which the fragments are held and the regional blood supply Each has a direct bearing on the tissue reaction by which bone union occurs A poor blood supply may delay the healing process or even lead to nonunion Incomplete immobilization of fragments may convert the highly specialized cellular callus into inert scar tissue with zones of cellular degeneration this is the chief cause of nonunion Incomplete reduction increases the callus requirement and thus prolongs the healing time

HISTOLOGY

Fracture healing is a vigorous orderly and highly specialized tissue reaction The process is continuous until there has been effected a complete restoration of structure and function Because a number of different changes are involved in the repair each taking place in response to a common stimulus a variety of developments histologically may be noted at any one time throughout the site of the injury It is convenient to distinguish three phases of cellular activity in this process which culminates in bone union the development of the provisional callus the formation of the primary callus and finally the union of the fragments by bone Later remodeling takes place to meet the stresses to which the restored bone is subject

PROVISIONAL CALLUS THE CELLULAR WELD

Within 48 hours of an injury the cells near the fracture which form the deep layers of the periosteum those which form the endosteum and those which line the haversian canals begin to proliferate (Fig 20 *A*) They assume the form of osteoblasts and lay down small scattered areas of bone As they multiply locally the periosteum and to a less extent the endosteum thicken to form an outer and an inner collar around the end of each fragment These collars become waves of proliferating cells which advance toward the other fragment (Fig 20 *B*) The masses of proliferating cells spread across the fracture gap meet and become confluent thus restoring cellular continuity between the fragments of bone (Fig 20 *C*)

Almost as soon as cellular proliferation starts cellular differentiation begins especially near the cortex of the bone where there is a richer blood supply Some of the cells near capillaries acquire the characteristics of osteoblasts and sparsely at first begin to lay down the trabeculae of bone In parts of the fast growing cellular mass which are more distant from the blood sup-

ply these proliferating cells differentiate into chondroblasts and form cartilage Mid way between the fragments where the two waves of proliferating cells meet very little cartilage is at first laid down here differen tiation is hardly begun until cellular union of the fragments has taken place

A fracture results in the death of a zone of bone on either side of the break because in compact bone the arrangement of capil laries and of the mechanism of nutrition for the cells beyond the capillaries is so limited that the source of nutriment is cut off (Figs 20 *A–D*) This zone of necrosis may be several millimeters in width With the death of the bone there will also have occurred death of the cells of the perios teum endosteum and the associated mar row cells This necrotic zone is subsequently resorbed and replaced by living bone (Fig 20 *D*)

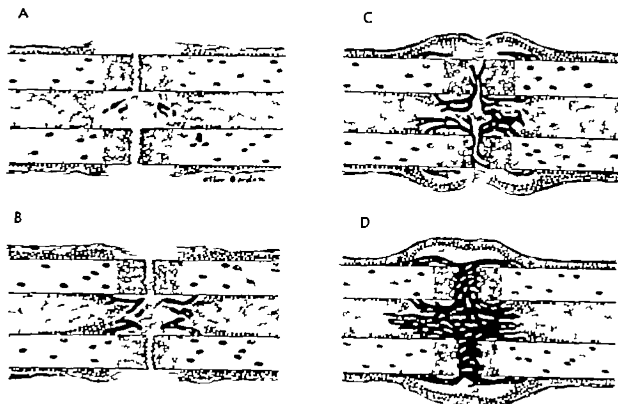


Fig 20 —Process of fracture healing. A within 48 hours proliferation of cells destined to form bone begins in the periosteum, the endosteum, and the lining layers of the haversian ca nals adjacent to the fracture Death has occurred in a zone of bone on either side of the break. B the proliferation of these cells results in the formation of a cellular wave which advances from each fragment into the fracture gap C the waves of proliferating cells spread across the fracture gap restoring the cellular continuity of the bone Cellular differentiation begins almost as soon as proliferation resulting in the formation of chondroblasts and osteoblasts and of car tilage and bone D the formation of cancellous bone directly by osteoblasts and indirectly by enchondral ossification results in bone union The zones of necrotic bone are resorbed and re placed by living bone

Cartilaginous Callus

With the completion of cellular union differentiation of the proliferating cells which develops slowly at the start of the repair accelerates rapidly throughout the tissue weld Change into chondroblasts pre dominates at first and masses of cartilage are formed Changes follow in the cartilage matrix which are similar to endochondral bone formation Chondrocytes the nearest bony trabeculae mature enlarge and se crete phosphatase Calcification of the

matrix ensues followed by ingrowth of vascular and fibrous tissue bundles rich in osteoblasts disintegration of the matrix and finally replacement by bony trabeculae Eventually the cartilage is almost entirely replaced by cancellous bone which bridges the fracture cleft between fragments and effects a cancellous bone union (Fig 20 *D*)

It has been pointed out that early in the repair bony trabeculae are formed by osteoblasts close to the cortical blood supply These trabeculae appear under the periosteum and along the endosteum in the medulla next to the zone of necrosis at the fracture site Sparse in the early stages of repair and slow to spread these trabeculae both periosteal and endosteal extend into the cellular portions of the callus as the blood supply is increased with the growth of the capillary system as osteoblasts invade the disintegrating cartilage matrix and as differentiation occurs in the proliferating osteogenic cells

The cells which originate in the deep layer of the periosteum usually constitute the major portion of the cellular wave which unites the fragments of the broken bone and eventuates in bone union They form what is termed the external or periosteal callus *Those cells which originate* in the endosteum (and also from undifferentiated marrow cells) form the internal or endosteal callus Commonly the external callus is the first to restore bone continuity between the fragments the internal callus may however prove of great importance when the external callus is deficient (Fig 20 *D*)

In the foregoing description of fracture repair special "osteogenic" cells are of chief importance in the formation of bone in the callus These osteogenic cells are described as arising from the deeper layers of the periosteum from the endosteum from the walls of the haversian canals and from undifferentiated cells of the bone marrow They are believed to differentiate into osteoblasts and chondroblasts which eventually form bone

In contrast there is a widely held theory that fibroblasts are the source of the bone producing cells According to this concept fibroblasts may arise not only from the same tissue layers from which the osteogenic cells arise but also from other connective tissues in the vicinity of the fracture The potentiality to differentiate into osteoblasts and chondroblasts attributed to fibroblasts in this theory is believed to be innate differentiation it is held awaits only the stimulation of a proper environment The subject remains a controversial one

Bone Union Resorption Replacement and Remodeling

Eventually by the mechanism described in the foregoing the cartilage is almost entirely replaced by bone and the fragments become solidly united by cancellous bone Remnants of cartilage may remain here and there to mark where formerly cartilaginous callus existed

Reference has been made to a zone of necrosis at the end of each fragment at the site of the fracture These necrotic zones result from the severance of capillaries which anastomose but little and from the disruption of the mechanism of nutrition beyond the capillaries caused by the injury Resorption of this dead bone proceeds as appositional new bone is deposited through the ingrowth of capillaries and osteoblasts from the nearby trabeculae of new bone Eventually the dead bone is entirely replaced by new bone Resorption and replacement are time consuming yet they are inevitable before the union of fragments is sound (Fig 20 *D*)

Once firm union has been established the trabecular texture of the weld is altered in conformity with natural stresses compact bone replaces cancellous bone in places and trabeculae are resorbed elsewhere until preinjury conformation makes the fracture site almost indistinguishable from the remainder of the original bone

THE INJURY CLINICALLY

Immediately after the fracture a hematoma forms between and about the adjoining fragment ends from torn vessels and sinuses in the bone and neighboring soft parts (Fig 21) There is more or less extravasation of blood into the regional muscles and fascia, and there may be extensive contusion and laceration Ecchymosis appears sooner or later At first swelling may be marked owing to hemorrhage and to edema resulting from hyperemia reflexly induced by the injury and from increased permeability of the injured walls of capillaries and venules On the second or third day blebs may appear and these may interfere with early definitive treatment The reaction of the tissue is slightly acid—sometimes markedly so—because of the products of tissue necrosis

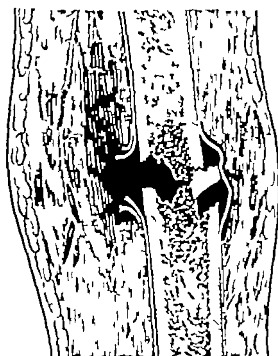


Fig 21 —Hemorrhage and edema accompanying fracture.

With prompt splinting of the injured part and elevation edema subsides in a matter of days Within 24 hours soft part repair begins Capillary endothelial loops bud from the neighboring vessels and revascularize injured soft parts Fibroblasts rapidly infiltrate the area repair takes place by granulation tissue As the debris resulting from tissue necrosis is removed by phagocytosis and excess fluid is absorbed by the developing vascular system the local tissue reaction gradually returns to the alkaline side of neutrality the change in reaction is usually complete in 2 weeks If injured muscles and fascia are too long inactive adhesions may form between them and bone and later these adhesions may seriously interfere with function through the binding of scar tissue Two to 3 weeks may be required for repair of the more severe soft part injuries during which time bone healing may have advanced sufficiently to allow supervised active exercise of neighboring muscles and joints while fixation of fragments is maintained

Of far more immediate importance than the injury to the bone or the muscles is the possible damage to nearby nerve trunks and main vessels Lowered blood flow from occlusion of the venous outlets of fascial compartments from arterial severance or from arterial occlusion due to vascular spasm may cause irreparable loss of structure and function to muscle groups In the upper extremity this is known as Volkmann s ischemia in the lower extremity the leg and foot may be similarly involved Determination of blood flow and the motor and sensory responses distal to the site of the injury are essential steps in the examination where fracture is suspected.

Open fractures with a small puncture wound created by the sharp end of a fragment of bone may run a very smooth course with prompt subsidence of swelling evidently due to evacuation of accumulations of blood through the wound. Extensive soft part laceration with or without sizable areas of avulsed skin may however have to take precedence over the fracture in the plan of treatment reduction being postponed until

the danger of slough and infection have passed

Rate of Healing

In adults the cellular weld has usually formed by the end of the third week provided that the reduction is complete the fixation of the fragments has been maintained and the blood supply is good Movement between the fragment ends seriously interferes with the blood supply and retards the formation of callus Under favorable conditions solidification of the callus through the deposition of cartilage and bone matrix begins to be apparent clinically after the second week following the reduction and is heralded by a rise in the local alkaline phosphatase Time is required for bone union Clinically the fragments of a broken bone may feel solidly united after a few weeks but roentgenographically the union may not be determined with certainty for several weeks or even months afterward In general the larger the broken bone the more compact is the bone that is present along the planes of fracture and the greater the displacement of fragments the longer the time required for healing Inadequate fixation of fragments seems to have a greater effect in the delay of healing than all other factors As a rule metaphysial fractures unite more quickly than shaft fractures

Age —Fractures heal with amazing rapidity in the newborn in infants union takes place more quickly than in children and in adolescents the healing is faster than in adults Femoral-shaft fractures in the newborn may be solidly united in a month whereas in an adult past middle life union may still be inadequate at 6 months

Local Blood Supply and Repair of Fractures

Certain portions of the skeleton are anatomically predisposed to delay in healing largely because the blood supply in the region is particularly vulnerable On the other hand certain areas are well recognized as having such a great capacity to unite that regardless of treatment fractures within them almost invariably unite and do so quickly Among the favored regions may be cited the clavicles ribs vertebral centra the calcanei pelvis etc In these areas the blood supply to each of the fragments is copious regardless of fracture and delayed union or nonunion is either rare or unknown Examples of portions of the skeleton notorious for having a vulnerable blood supply are the femoral neck, the carpal navicular, and the portion of the tibia about the junction of the lower and middle thirds

The work of Johnson has shown that the blood supply to a long bone comes from three sources (1) the nutrient arteries which enter the medulla through one or several foramina in the diaphysial cortex and send large terminal branches to each end of the bone (2) the metaphysial arteries and (3) the periosteal arteries The metaphysial vessels reach the bone by way of attached ligaments and through the insertions of tendons They course to and from the medullary canal through multiple small foramina in the cortex and supply the epiphysis and the metaphysis The periosteal vascular system covers the entire cortical surface of the bone supplying the periosteum and the outer third of the diaphysial cortex The tibial blood supply (Fig 22) is typical of the long bones Because the distal half of the tibial shaft is largely dependent on the nutrient artery for its blood supply fracture in this region which severs the artery as it courses distally along the medullary canal results in ischemia of the shaft portion of the distal fragment Unless other factors are favorable and the period of protection is prolonged delayed union or even nonunion is prone to occur In contrast in the epiphysial portions of the tibia abundantly supplied by metaphysial vessels union of fractures is rarely delayed The tibial blood supply is typical of that of the long bones except the vascular distribution of the femoral neck and head

Fracture of the femoral neck may cut

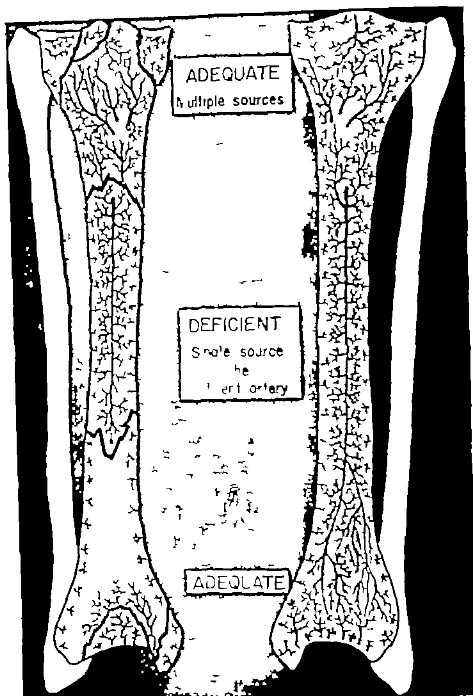


Fig 22.—The tibial blood supply

off or may seriously and permanently impair the blood supply of the neck or head or both (Fig 23) The vessels reach the neck by way of the capsular and ligamentous attachments at its base They course proximally and superficially along the neck may become occluded by thrombosis from the pressure of malaligned fragments or they may be damaged by too zealous manipulation Nonunion absorption of the neck and avascular necrosis of the head are traceable in large measure to the inade

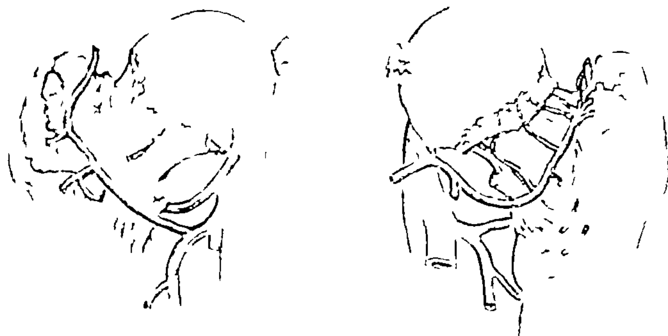


Fig 23 —Left the blood supply of the femoral head and neck anterior view Right posterior view (Drawn from Lanz T von and Wachsmuth W *Praktische Anatomie* [Berlin Julius Springer 1938] Vol I pt IV)

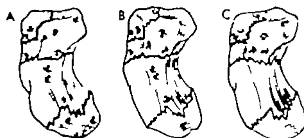


Fig. 24 —Types of navicular blood supply and their influence in fracture: A vessels enter each third of the bone B there are no vessels entering the proximal third from without C no vessels from without enter the proximal two thirds Fractures in portions of the bone devoid of independent blood supply will be slow to unite

giving off branches for the nutritional supply of the neck and finally enter the head at its junction with the neck. These vessels carry the main blood supply to the head A limited amount of blood enters the head and leaves it by way of the ligamentum teres The vessels of the head and neck may be severed at the time of the fracture they quacy of a vulnerable circulatory system

Equally precarious from the standpoint of vascularity is the position of the proximal fragment in fracture of the carpal navicular because not only may the fracture present difficulties in reduction and in fixation but the blood supply may be extremely vulnerable (Fig 24) In approxi

mately one third of the cases of this fracture there are few or no nutrient arteries pierc ing the cortex of two thirds of the bone in one third, not one artery enters the proximal third through the cortex. As a result, union must necessarily be slow in a high proportion of cases fixation must be adequate and prolonged if healing is not to be further retarded

Location of Fracture

The time necessary for the healing of a fracture also varies with the particular bone involved and with the site of the fracture in that bone provided that conditions for healing are otherwise favorable For exam ple impacted fractures of the neck of the humerus or metacarpal-shaft fractures require only 3 weeks for a substantial union many wrist and ankle fractures unite in 6–8 weeks many tibial shaft fractures do not heal solidly before 14–22 weeks most femoral-shaft fractures need 5 or 6 months for substantial union and many fractures of the femoral neck are not certainly united for a year or more

Evidence indicates that this wide varia tion in the rate of healing in different bones is broadly the result of five factors the local blood supply the normal density of the bone at the site of fracture the extent of the fracture the quality of the reduction and the firmness of the fixation of the fragments during repair Adverse conditions in several of these respects may exist, and in consequence the time schedule may be upset and bone union may be delayed for months and months Or the repair process may even become arrested and the fracture go on to frank nonunion

Type of Fracture

In general, oblique and spiral fractures unite more quickly than those which are transverse (Fig 25) presumably because a richer medullary and periosteal blood supply and a more ample source of osteogenic cells are available in the former types Moreover transverse fractures are often comminuted and in them, death of bone is often more extensive

The free "butterfly" fragment and the free "intermediate" fragment (Fig 26) have only their periosteal blood supply (Johnson has shown that the periosteal blood supply nourishes the outer third of the cortex only) both the nutrient and the metaphysial arteries to the free fragment have been severed Of 5 consecutive pa

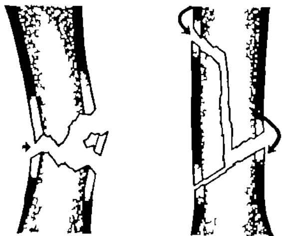


Fig 25 —Three of the more common types of fracture Left transverse Right oblique and spiral

tients in a series of tibial shaft fractures in which a free intermediate fragment was present both fractures failed to unite in 2 after manipulative reduction and external fixation these 2 patients were operated on for nonunion There is a strong case for anticipatory surgery in this group of frac tures Open reduction to assure anatomical restitution and internal fixation which is absolute together with supplementary bone grafting seem clearly indicated unless ana tomical reduction is possible by manipula tion and external fixation can be provided which is unusually efficient

Reduction and Repair of Fractures

Anatomical restoration of the broken bone reduces to a minimum the size of the cellular weld and the callus required to

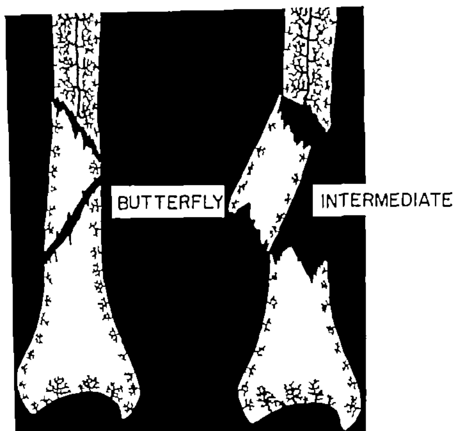


Fig 26 —Two of the less common types of fracture—butterfly and intermediate

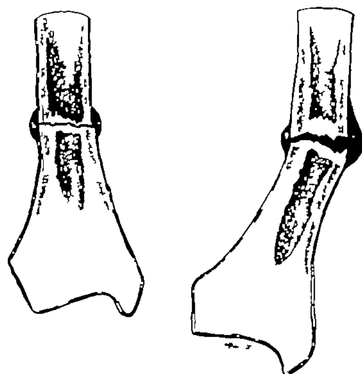


Fig 27 —Relation of the degree of reduction of the fracture and the amount of callus required Left anatomical reduction Right large callus requirement and slow union

bind the fragments together (see Fig 27) Each cell group destined to participate in the formation of the callus is in the most advantageous position to reproduce its own tissue—the fibroblasts from the periosteal connective tissue the osteogenic cells from the deeper layers of the periosteum and the endosteum and the endothelial cells from the new vascular system—all essential to a vigorous cellular union.

proach in importance faulty fixation as a cause of delayed union or nonunion and no factor is more conducive to rapid healing of bone following fracture than absolute immobilization of fragments

In nonoperative fracture management circular molded splints of plaster-of-paris are uniformly successful when properly applied and when replaced as required—for example soft part atrophy destroys the ef

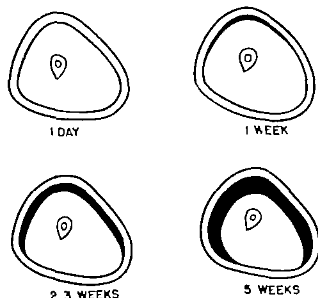


Fig 28 —Soft part atrophy and immobilization of fragments by external plaster-of paris fixation

Fixation and Repair of Fractures

Firm fixation of fragments protects from injury the highly specialized actively proliferating cells of the forming callus By such fixation the new and tender capil laries and arterioles of the rapidly developing blood supply are protected from tension compression bending and twisting Firm fixation when feasible allows early func tion which in turn increases the blood flow and at the same time prevents adhesions between muscle and bone and joint capsule and bone Witness the brilliant results from intramedullary nailing when this form of fixation is properly applied in selected cases and when it is supplemented by early use of the part

No single factor can even remotely ap-

fectiveness of the external fixation (Fig 28) *Failure to include in the splint the* contiguous joints—proximal as well as distal to the fracture—results in motion at the site of the fracture the same is true unless the adjoining segments of the limb above and below are included and are held at an angle of at least 45–60 degrees with the fractured member This prevents rotation of the limb from causing motion at the site of fracture (Fig 29) Too short a splint no matter how accurately applied will not ef fectively immobilize the fragments.

Delayed Union and Nonunion

It will be apparent from the foregoing that in part the rate of healing of a frac ture will depend on factors inherent in the

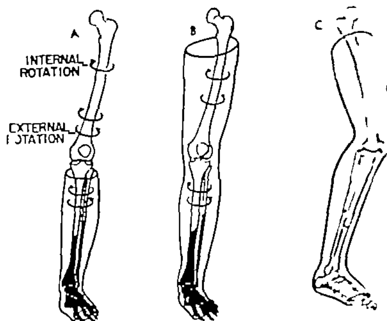


Fig 29 —The effect of the position in which the joints contiguous to a f... the immobilization of the fragments by external plaster-of paris fixation A ... fixation C adequate fixation no torsion

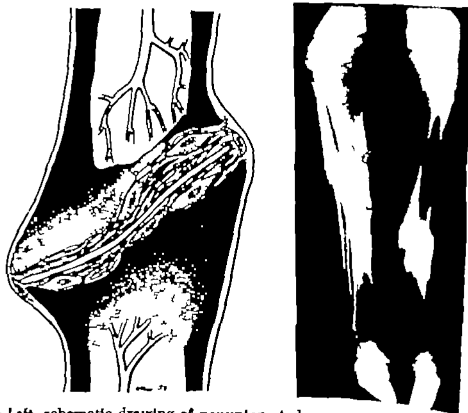


Fig 30 —Left schematic drawing of nonunion A dense avascular ... nous hyaline and fibrinoid degeneration is interposed between fibrocar... tilage on broadened sclerotic fragment ends The medullary canals ... by dense bone Right roentgenogram of nonunion

particular bone which has been broken and in the type and location of the fracture of that bone Even more convincing is the clinical evidence that delay in healing and failure to heal are due to factors clearly within the control of the surgeon—factors which can be avoided

union for any normal activities in 12 weeks The tibial fracture unites slowly because the proportion of dense bone at the site of fracture is high and the local blood supply is limited. However its rate of union is not abnormal it is not to be classified as a case of delayed union

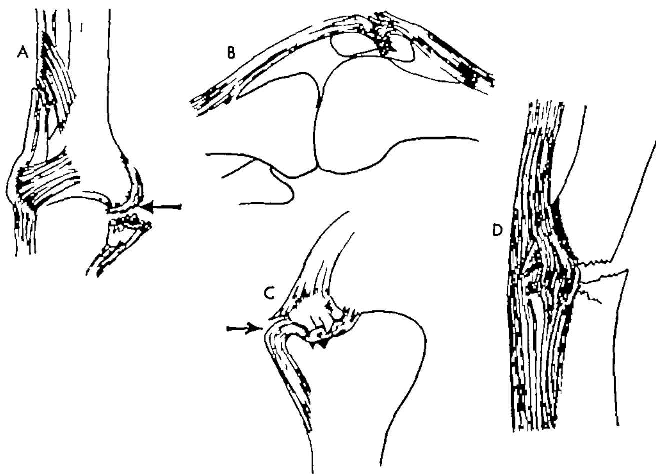


Fig 31 —Interposition of tissue causing nonunion. A, fracture of medial malleolus with fibers of deltoid ligament interposed between fragments B fracture of patella with fibers of the quadriceps tendon interposed between fragments C fibers of the ulnar collateral ligament between ulnar styloid and shaft D muscle between fragments of humerus

SLOW HEALING —Many fractures heal slowly despite the best treatment In an adolescent a closed comminuted transverse fracture of the tibia at the junction of the middle and distal thirds anatomically reduced and held in absolute immobilization may require 22 weeks for bone union that is adequate for unrestricted use of the limb In contrast an impacted fracture of the humeral neck corrected to preinjury shape and protected from recompression until united may have adequate bone

DELAYED UNION —When healing is retarded beyond the normal rate for a given fracture by factors within the control of the surgeon union is delayed Eventually the retarding factors will be overcome and union will occur provided that the fragments are immobilized firmly and constantly and that displacement is not too excessive

NONUNION —Nonunion is fundamentally different from delayed union Here the repair process has stopped—completely

and finally A dense avascular acellular zone of mucinous hyaline and fibrinoid degeneration is interposed between fibrocartilage and hyaline cartilage on broad ened sclerotic fragment ends The medul lary canals on either side are occluded by dense bone (Fig 30)

Such failure of the natural process of repair is almost always preventable It is in most instances due to incomplete fixa tion of fragments or too short a period of fixation or both Other contributory factors include reductions which leave too great a callus requirement, distraction of frag ments interposition of soft parts between fragments and overzealous discarding of bone fragments leaving gaps too large for natural repair Hindering factors of a con stitutional nature include such diseases as rickets scurvy osteomalacia cachectic states and neoplasms

Distraction and Retarded Union

Distraction or the pulling apart, of frag ment ends in the long axis of the bone is the result of excessive traction almost always skeletal in type Distraction is almost sure to result in retardation of the healing proc ess It is a much less common factor today since skeletal traction has been largely replaced by other methods

Interposition and Retarded Union

Ligament muscle fascia periosteum tendon or dense avascular bone fragments when interposed between fragments may prove to be insurmountable obstacles to manipulative reduction they may even cause nonunion Open reduction alone may suffice to make repair possible in a reasonable period of time (Figs 31 and 32)

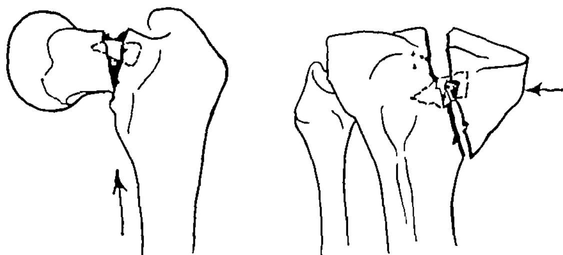


Fig 32.—Interposition of dense avascular bone fragments preventing satisfactory reduction and retarding or preventing bone union

Overzealous Discarding of Bone Fragments during Debridement

By discarding sizable intermediate frag ments of bone which are devoid of blood supply and devitalized by trauma and producing a large gap in the bone as a result the well meaning surgeon may create problems in bone repair with which even Nature cannot cope successfully (Fig 33) It is far safer to run the risk of delayed union and infection than to court nonunion and have to face the difficult surgical problem of osseous bridging of bone defects

Metallic Internal Fixation and Retarded Union

Internal fixation when it is made of inferior material is improperly applied, is faultily constructed or inadequately supplemented by external fixation and restriction of activities may hinder rather than promote the sound healing of bone Inert metallic appliances of sufficient strength of sound construction mechanically applied according to correct techniques and adequately supplemented by external support, may yield brilliant results

Infection and Repair

Among the deterrents to the healing process infection may take high rank because the reaction to bacterial toxins leads to the formation of dense avascular scar tissue and death of bone Complete reduction and prolonged absolute fixation of fragments when combined with debridement and early closure the maintenance of the normal blood volume normal blood protein content, and normal hemoglobin levels will almost invariably result in bone union.

There is clear evidence that the foundation for delayed union or nonunion is laid in the earlier weeks of treatment and that in most instances these complications could be avoided by means at the surgeon s disposal.

It is also true that the principles of treatment which are most favorable to the healing of fractures give the best results anatomically and functionally

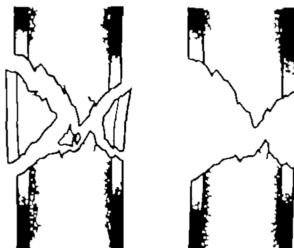


Fig 33 —Discard of fragments at debridement, with impending nonunion.

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5  Delayed Union and Nonunion of Fractures

MUCH PROGRESS has been made in the management of long-bone fractures during the twentieth century Accurate diagnoses have been possible with proper x ray tech niques methods of external splinting have been perfected surgical techniques have been improved the metals used for internal fixation have been standardized and the care of the whole patient has been en hanced. *But as these advances have been* made nonunion of bone has actually been on the increase In general the common causes of nonunion are lack of reduction of the fracture and inadequate immobiliza tion *but a common offender is the surgeon* himself Because of the present practice of teaching progress in fracture management the student—particularly the postgraduate student, who may or may not be grounded in fundamental surgical principles—is ex posed to the newer and at times not suffi ciently tested operative techniques Quite naturally but at times without good rea *son the ill-trained surgeon will operate on* long bone fractures many of which would have healed with simple reduction and im mobilization In many instances harm is done—by the use of inadequate or im proper incisions poor internal fixation and improper postoperative care any of which may lead to delayed union or nonunion of bone When such errors in judgment and poor results occur both the teacher and the student must share the responsibility

When bone fails to heal after fracture the cause in an extremely high percentage of cases is a local one Generalized bodily disturbance does not cause nonunion of bone except in cases of extreme malnutri tion extreme vitamin deficiency or intrin *sic bone disease*

Fractures of certain long bones—name ly fractures of the femoral neck, the fem oral shaft the lower shaft of the tibia and at times the humeral shaft—require a *longer period of time to unite than do frac-* tures of other bones The slowness of union of fractures in the areas listed is generally attributed to lack of adequate blood supply to the part because in these instances the fracture usually occurs at the level of or beyond the entrance of the nutrient artery and circulation to the fracture surfaces is cut off Therefore unless prompt and accu rate reduction is carried out healing of bone may be delayed and nonunion may result The local causes of delayed union or nonunion are

1 Inadequate reduction of the fracture
2. Inadequate external fixation
3 Trauma to soft parts which inter

feres with circulation to the bone fragments

4 Improper operative interference causing trauma to bone ends and interference with blood supply

ture of a particular bone must be immobilized but the arbitrary periods shown in the table can be accepted for a working formula, particularly if internal fixation is not applied

1 Phalanges	A few days to 2 weeks
2 Metacarpals	2–3 weeks
3 Carpal bones other than the navicular	3–6 weeks
4 Carpal navicular	10–16 weeks
5 Forearm bones:	
a) Children	6–8 weeks
b) Adults	8–14 weeks
6 Humeral shaft	8–12 weeks
7 Clavicle:	
a) Children	3 weeks
b) Adults	4–6 weeks
8 Metatarsal bones	3–4 weeks
9 Tarsal bones	6–8 weeks
10 Tibia	
a) Without fracture of the fibula:	
(1) Young children	6 weeks
(2) Older children and adults	8–16 weeks
b) With fracture of the fibula	
(1) Young children	6–8 weeks
(2) Older children and adults	12–20 weeks
11 Femur	
a) Children	6–8 weeks
b) Older children and adults	12–24 weeks

5 Inadequate internal fixation
6 Too much "hardware" — plates screws bands etc (Fig 34)
7 Improper application of metal for internal fixation
8 Distraction of bone fragments due to improperly applied traction
9 Too early motion of the injured part
10 Too early weight bearing on the injured extremity
11 Sacrifice of bone fragments in open fractures
12 Infection

The larger the bone the longer the time required for healing in most instances The fractured phalanx will be stabilized and the finger can be used in a few days without fear of delayed healing but a fracture of the femur must be protected for months because of the size of the bone its weight bearing function, and very large muscle attachments which exert pull on the fractured fragments

There is no rule as to how long a fracture of a particular bone must be immobilized but the arbitrary periods shown in the table can be accepted for a working formula, particularly if internal fixation is not applied

Nonunion (clinical) of fractures does not occur in the following

1 Vertebral body of the spine
2 The skull
3 The scapula

The time factor in the healing of fractures may be the most important phase of all fracture management, and courage on the part of the surgeon and co-operation by the patient are required to continue with immobilization until bone heals Immobilization must be complete Plaster of paris is the most effective means of providing such fixation Braces which are worn part time do not give uninterrupted fixation and often give the patient a false sense of security

No two fractures are alike as to cause and resultant deformity and the management of no one fracture can be exactly comparable to that of another This statement can be applied to an even greater degree in regard to nonunion of bone The causes of nonunion listed below are the common ones but in certain cases a combination of



Fig 34 —How much metal can bone tolerate? The original fractures sustained in an automobile accident were located at the base of the femoral neck the upper one third of the femur and the midshaft of the femur The third fracture developed in the lower third of the femur from minor trauma to porotic bone during convalescence from the original injury Left the result of treatment nonunion of the base of the femoral neck and a refracture of the distal portion of the shaft. A sterile abscess developed over the plates in the lateral aspect of the femur Eventually the sterile abscess was evacuated hardware removed and wound closed The fractures united except for the one at the base of the femoral neck. Right 2 years after union of femoral shaft and insertion of a Vitallium prosthesis for the ununited femoral neck fracture Patient, now ambulatory and walking with a cane was perfectly able to carry out his duties as a hotel executive

factors may exist Soft tissue scar bone loss and infection—all play a part in the delayed healing of many open fractures In recent years as operative treatment of fractures has become more frequent improper operations have become a major cause In an analysis of 55 closed fractures which eventually resulted in operation for correction of long-standing nonunion the causes were listed as follows

Inadequate closed reduction	16
Inadequate external fixation	15
Improper operative interference	15
Distraction of fragments	6
Soft tissue trauma	2
Malnutrition	1

In 18 open fractures the causes of nonunion were listed as follows

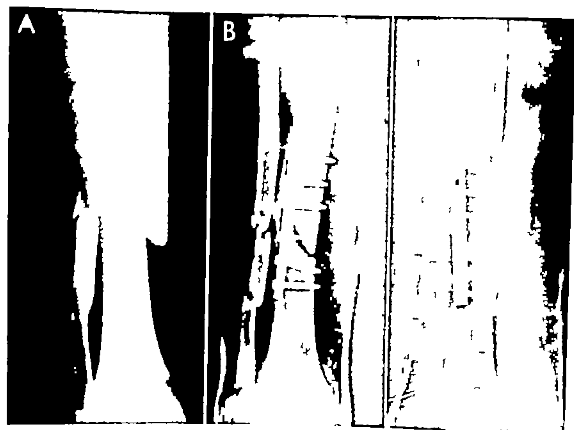
Bone loss	8
Improper operative interference	4
Soft tissue trauma	2
Distraction of fragments	2
Inadequate external fixation	1
Poor reduction	1

It is discouraging to note that improper operative interference is high in each group

At times it may be difficult to determine whether one is dealing with delayed union and occasionally one cannot be sure that nonunion actually exists

The presence of *delayed* union must be determined almost entirely by the x ray film (Fig 34-1) Certain bones give evidence of healing in more or less prescribed periods of time The best evidence of bone healing is callus formation as shown by the film Calcification of periosteum is not true callus formation The more accurately a fracture is aligned the less demand there will be for callus In such a case a gradual obliteration of the fracture line without loss of position, and the absence of unusual bone atrophy or excessive sclerosis at the fracture site are the best evidences of progressive bone healing.

There is no reliable clinical test for delayed union As a fracture is healing manual tests for motion should not be made at the fracture site because any movement will interrupt the new bone bridge which is uniting the fracture


A
B

Nonunion of bone occurs when the re pair process has stopped completely and it may be suggested by the following clin ical findings

1 Pain on use of the extremity
2. Progressive bowing of the extremity
3 Edema of the extremity

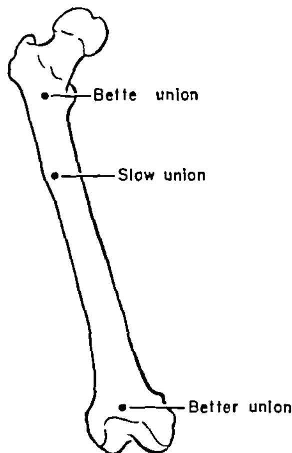


Fig 35 —Diagram indicating rate of heal- ing in parts of a bone (femur)

4 Increased surface temperature at the fracture site

By roentgenogram the following should be looked for to determine the presence of nonunion

1 Excess (false) callus production at the fracture site
2. Gradual bowing at the fracture site
3 Unusual sclerosis at the fracture site
4 Unusual bone atrophy below and above the fracture site

While definite rules cannot be put down as to the exact technique of management of any group of cases of nonunion of bone certain considerations are always necessary and certain principles must be adhered to When confronted with an ununited frac ture the surgeon must ask himself the fol lowing ten questions

1 *Which bone and what part of the bone are involved?*

The trochanteric area and the supra condylar area of the femur will unite more promptly than will the shaft of the femur because the blood supply is more abundant in the former areas (Fig 35) The same applies to the upper and lower ends of the other long bones (Fig 22 p 38) The fem- oral neck and the carpal navicular are no- toriously slow in uniting

2 *How long has nonunion existed?*

The longer the nonunion has existed the greater the sclerosis of bone ends and atrophy of the shaft beyond the fracture line (Fig 36) Sclerosed bone will require a long time to revascularize even if it is covered by "fresh" bone and nourished by a good muscular covering.

3 *What is the condition of the soft parts?*

Scar in skin (Fig 37) subcutaneous tissue and muscle will preclude good circu lation to the fracture and to the bone graft The graft must therefore be inserted through an incision over the most viable soft tissue (Fig 38)

4 *What is the condition of the joints above and below the site of fracture?*

Immobile joints will add strain to the fracture site Therefore after the graft is applied the fracture must be protected un- til there is solid union Medullary fixation has allowed much earlier joint motion after operations for nonunion

5 *Is the fracture in satisfactory align ment?*

An ununited fracture in good align ment need not be mobilized by excising scar at the fracture site Fibrous union gives some stability and subperiosteal iliac bone may be all that is required to promote union (Fig 39)

6 *To what degree is there sclerosis of bone ends at the fracture site?*

Sclerosed bone with excessive callus formation need not necessarily be com



Fig. 36 —Sclerosis of bone in a manufacturer aged 52. A, 2 years after open fracture complete nonunion of tibia B 1 year after grafting and 3 years after injury complete healing. The onlay graft was removed from the proximal fragment. Iliac bone slabs were also packed about the fracture site

Anterior tibial M
Anterior tibial A
Extensor digitorum com M
Interosseous membrane
Deep peroneal N

Fig 37 (left) —A scar over the anterior aspect of the tibia (man, aged 23) contraindicates an operative incision in this area A lateral approach (Fig 38) can be used

Fig 38 (right) —Lateral approach to the tibia.



Fig 39 —Nonunion of 6 months duration following faulty application of plate and screws in the tibia of a housewife aged 26 **A** 6 months after injury and operation **B** 4 months after removal of plate and screws and subperiosteal application of iliac slabs of bone posteriorly mesially and laterally bone has healed. **C** 7 years after bone graft complete recovery

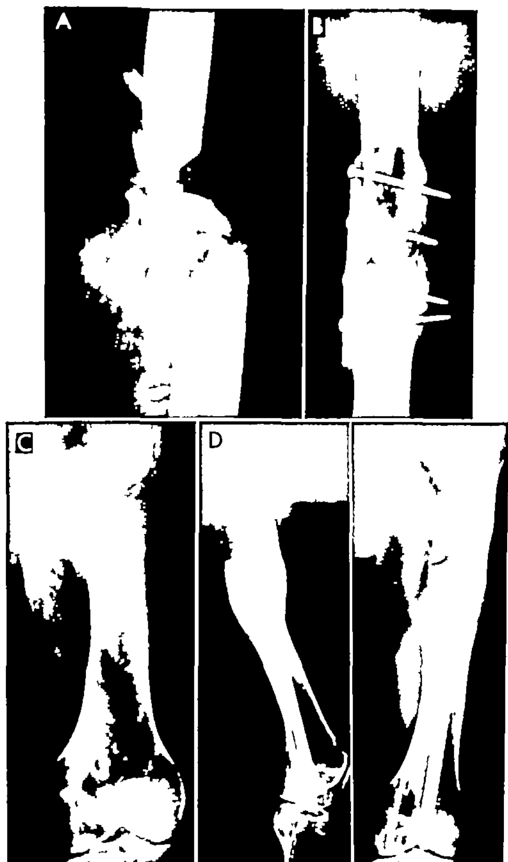


Fig 40 —Use of medullary nail in old ununited infected fracture of femur and extreme bone loss extreme bone sclerosis and 3-inch shortening, secondary to gunshot wound in a soldier aged 29 A, wound shortly after injury B 4 years later after several attempts at bone grafting. C 5 years after wound following removal of screws and graft D bone union without infection following medullary nailing 8 years after injury

pletely excised but the shaft should be re shaped by trimming down the excess sclerotic area before applying the graft Such reshaping will enhance the local circulation and result in easier wound closure (Fig 40)

7 *To what degree is there osteoporosis of bone below and/or above the fracture site?*

Osteoporosis calls for as early use of the extremity as is consistent with healing of the ununited fracture (Fig 41) Until weight is borne or joint motion can be initiated circulatory exercises by the use of an oscillating bed may be of benefit



Fig 41 —Fracture of upper shaft of left femur and generalized osteoporosis as a result of anorexia nervosa in a housewife aged 48 A, nonunion following minor trauma superimposed on extreme osteoporosis secondary to malnutrition (vomiting of 30 years duration) B bone union 1 year after open reduction and medullary stabilization with bone-bank rib added. Medullary fixation was supplemented by external plaster fixation necessary because a supracondylar fracture was produced during preparation for insertion of medullary nail

8 *To what degree is there bone loss?*

Bone loss is at times the most severe deterrent to bone healing and it frequently follows gunshot wounds or ill advised debridement To promote union bone must be replaced by grafting or the shaft must be shortened at the fracture site (Fig. 42)

9 *To what degree is there shortening of the injured bone?*

Bone lengthening has been largely abandoned as an operative procedure since it is better to obtain union even though a considerable degree of shortening must be accepted Shortening of the lower extremity can be compensated for by a lift on the shoe If the shortening is too great amputation can be done at the point of election and a prosthesis used if bone union can be established (Fig 43)

10 *If union can be established will the patient have a useful extremity?*

If despite bone union there is severe painful limitation of joint motion with marked shortening not correctable by an elevated shoe amputation may be the procedure of choice

NONUNION OF THE FEMORAL SHAFT FRACTURES

In frequency nonunion in fractures of the femoral shaft occurs second only to those of the tibia In 27 cases of nonunion

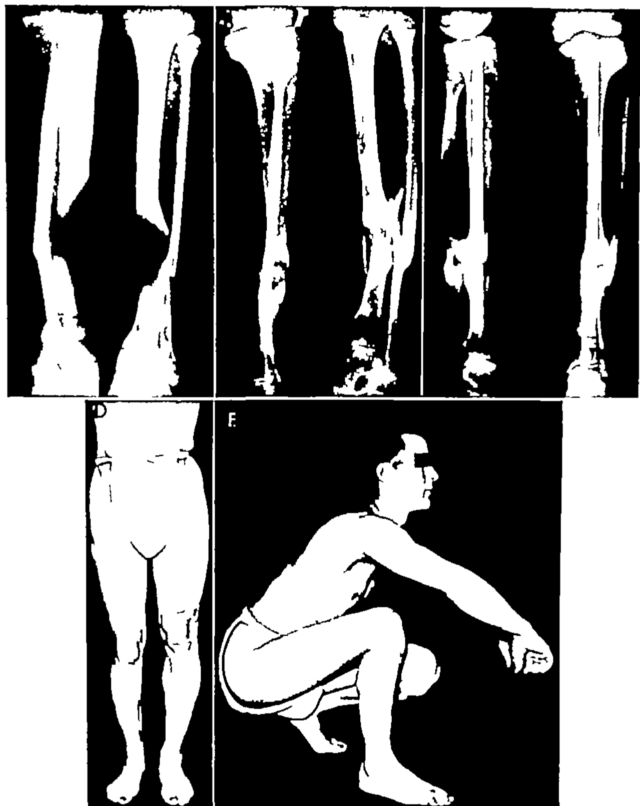


Fig 42.—Nonunion of right tibia with deformity in soldier aged 23 A extensive bone loss of tibia following open fracture union of fibula of 2 years duration B 1 year after attempted bone graft. C 5 years after injury and 1 year after medullary nailing and graft bone union D and E end result: bone union 1 inch shortening good knee function

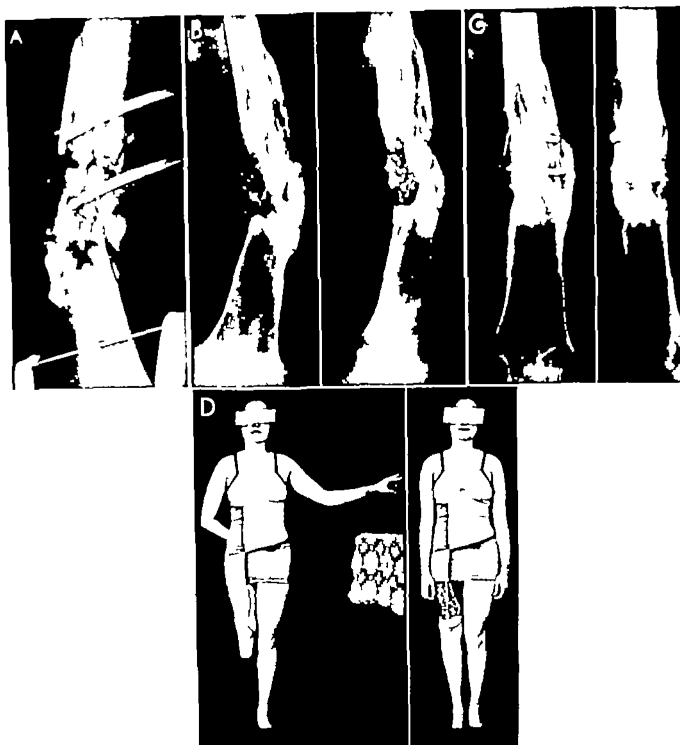


Fig 43 —Producing union by bone shortening. A gunshot wound of femur (woman aged 17 in the home) resulting in gangrene of foot and distal leg and followed by amputation bone loss and nonunion of femur B 1 year later draining sinus nonunion of femur C 2 years after injury (femur had been shortened and secured with 2 screws) union obtained. D 5 years after injury union of the shortened femur and a mobile knee prosthesis worn satisfactorily

of the femur the causes of nonunion were as follows

Inadequate external fixation	9
Faulty operative interference	6
Distraction of fragments from too much traction	5
Bone loss	4*
Poor reduction	2
Malnutrition (generalized)	1

plication of iliac bone succeeded in some cases where the onlay graft failed but it required prolonged immobilization of the extremity afterward (Fig 44)

If the soft tissues will permit a high per centage of cases of nonunion of the femoral shaft can be successfully treated by the medullary nail and the addition of subperiosteal iliac or tibial bone (Fig 45) Bank bone may be used at times Postoperative care will depend greatly on the condition of the soft tissues the quality of the bone to be stabilized the mobility of the joints above and below the fracture and the return of muscular strength to the quadriceps and the hamstring groups of muscles If good stability is obtained by the nail and muscular control is satisfactory partial weight bearing with crutches can be allowed as soon as soft tissue is healed When stability of the fracture is in doubt

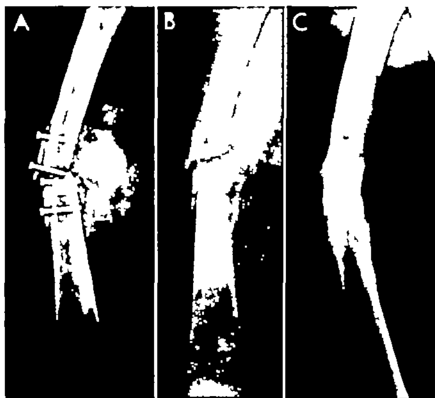


Fig 44 —Nonunion and osteomyelitis of femoral shaft following closed fracture and two attempts at bone grafting in a man aged 22 A, condition of femur at admission 2 years after injury nonunion and a septic wound B after removal of screws and sequestra C bone union 1 year later after introducing iliac bone grafts through a separate posterior incision and 8 months of plaster fixation (see Fig 45)

Treatment of Nonunion of Closed Femoral Fractures

Since the introduction of medullary nailing nonunion of the femur has been less frequent and when it has occurred it has been more easily corrected by intramedullary fixation Before the use of the medullary nail the onlay bone graft or the subperiosteal application of iliac bone was used The onlay bone graft was frequently followed by failure The subperiosteal ap-

* Open fractures.

the medullary nail may be supplemented by a walking spica (Fig 46) Crutches should be continued until bone union is established This period of time will vary from 4 months to 1 year or perhaps longer



Fig 45 —Comminuted fracture of upper shaft of femur (housewife aged 34) nonunion resulted. A, the original fracture B 2 years after insertion of medullary nail which broke 18 months after it was inserted because it was of too small diameter and was not inserted far enough down the shaft nonunion C after removal of screws and broken nail and the insertion of a larger (12 mm) nail which reached to the level of the adductor tubercle and of bone grafts

Treatment of Nonunion of Open Femoral Fractures

Ununited open fractures of the femoral shaft offer a serious problem because usually there has been extensive damage to the soft tissues resultant scar formation possibly latent bone infection and not infrequently bone loss

The medullary nail is by far the best means of handling such problems Before inserting the nail it is usually wise to eliminate all sinuses and sequestra insofar as possible If drainage persists in spite of what was considered to be adequate debridement the surgeon may be justified in introducing the medullary nail because often stability of a fracture will not only encourage healing of bone but will also diminish the reaction to infection and it may even encourage closure of a draining sinus Bone grafts may be added through a separate incision (Fig 47)

NONUNION OF CLOSED FRACTURES OF TIBIA AND FIBULA

If the ununited tibia is in good alignment and the soft tissue in good condition

it is probable that subperiosteal iliac bone will work successfully in promoting union If the fibula is united in malposition and causing stress at the site of the tibial fracture it should be osteotomized possibly shortened and stabilized with a Rush pin.

If the fracture of the tibia is disaligned the surgeon will of necessity expose and



Fig 46 —A "walking" plaster spica supplementing medullary fixation for an ununited fracture of the femoral shaft of 2 years duration. Spica was applied in a standing position and was worn for 6 months without difficulty by a housewife aged 34

mobilize the fracture and osteotomize or shorten the fibula (Fig. 48) He may use an onlay tibial graft from the proximal fragment or from the opposite tibia. This graft should be secured by four screws to the tibia and iliac bone should be added subperiosteally posteriorly mesially and laterally Stabilizing the fibula by the Rush pin gives added strength In any case prolonged external fixation by means of plaster is necessary

Another method of handling this type of fracture is by medullary fixation of the tibia in conjunction with bone grafting It is possible that the Lottes nail will be the answer to this very difficult problem (Fig 49) Prior to the use of the Lottes nail, the author introduced in 7 patients the clover leaf Küntscher nail retrograde through the knee joint (Fig 50) All 7 patients had long-standing nonunion, from 2 to 12 years Where all other methods had failed this procedure seemed justified In no case was harm done to the knee joint, and the procedure worked successfully in 6 of the 7 patients One patient required amputation

NONUNION OF THE TIBIA AND FIBULA SECONDARY TO OPEN FRACTURES

In the management of the ununited open fracture of the tibia and fibula (Fig 51) much depends on the condition of the skin, subcutaneous tissue and surrounding muscle Very often scarring will be so extensive anteriorly over the tibia that a direct incision in this area will be impossible and the approach must be lateral or posterior

A full thickness skin graft over the scarred tibia may increase nutrition to the area, but it is doubtful that the routine anterior approach to the ununited tibial fracture can be used in many cases even after a skin graft There is considerable doubt as to whether a full thickness skin graft actually nourishes the bone as does normal skin and subcutaneous tissue

NONUNION OF FOREARM FRACTURES

Nonunion of the forearm bones occurs third in frequency following nonunion of the tibia and the femur Nine cases in a series of 73 occurring in all long bones involved the radius and/or ulna Of the 9 cases 3 were open fractures and 6 were closed In 7 cases the soft tissues were in excellent condition at the time of operation.

Of the 6 closed fractures 2 were treated

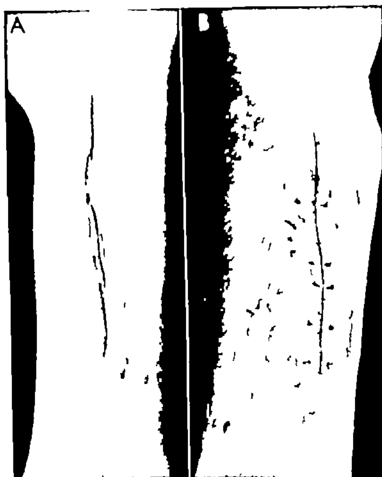


Fig 47 —The use of a separate incision for introducing a bone graft in nonunion of the femoral shaft and a draining sinus in a roofer aged 31 A an old open wound in the posterolateral aspect of the thigh B an incision over the anteromesial aspect of the thigh through which iliac bone had been introduced to bridge the area of nonunion in the shaft of the femur



Fig 48 —Segmental fractures of tibia and fibula following extensive open injury to bone and soft tissue 2 years previously in a man (a teacher) aged 59 A, nonunion of the disaligned upper tibial fracture B 3 years after injury and 1 year after onlay tibial graft (removed from proximal fragment) and iliac bone. To correct deformity the fibula was osteotomized at distal fracture

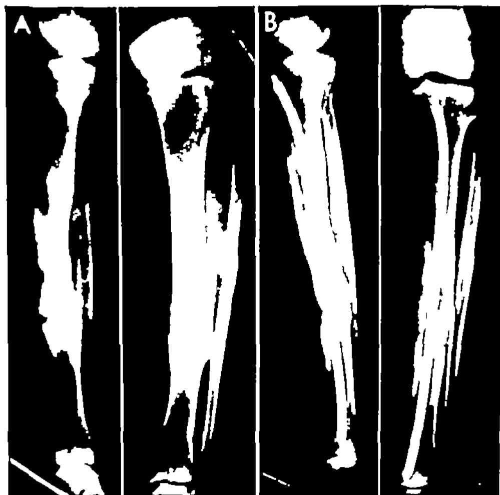


Fig 49 —A, marked sclerosis of tibia associated with failure of healing after open reduction and internal fixation and later a bone graft both of which failed in a man aged 23 B 1 year after insertion of the Lottes nail and iliac bone grafts union established



Fig 50 —Pseudarthrosis lower-third tibia and fibula deformity following open fracture of tibia and fibula 2 years previously in a laborer aged 74 A, complete nonunion of tibia and fibula and deformity of 2 years duration. B end result, 1 year after open reduction, medullary nailing, and iliac bone grafts C (left) preoperative view showing deformity (right) postoperative—complete correction, with bone union



Fig 51 —Nonunion of lower tibia and fibula of 16 years duration in a nurse aged 33 A, the original open fracture sustained at age 17 16 years before admission. B condition of bone and ankle joint at time of admission complete pseudarthrosis of both tibia and fibula deformity and traumatic arthritis of the ankle joint C 13 months after osteotomies at fracture sites application of plate and screws to tibia and of iliac bone about both tibia and fibula. Note that screws in proximal fragment have broken indicating failure of bone to heal D 8 months after removal of plate and screws and application of iliac bone about fracture sites of tibia and fibula and continuous plaster fixation union established The ankle joint realigned but traumatic arthritis persisted although patient was symptom free and had a good range of ankle motion.



Fig. 50 —Pseudarthrosis lower-third tibia and fibula deformity following open fracture of tibia and fibula, 2 years previously in a laborer aged 74 A, complete nonunion of tibia and fibula and deformity of 2 years duration. B end result, 1 year after open reduction medullary nailing, and iliac bone grafts C (left) preoperative view showing deformity (right) postoperative—complete correction with bone union.



Fig. 51 —Nonunion of lower tibia and fibula of 16 years duration in a nurse aged 33 A the original open fracture sustained at age 17 16 years before admission B condition of bone and ankle joint at time of admission complete pseudarthrosis of both tibia and fibula, deformity and traumatic arthritis of the ankle joint. C 13 months after osteotomies at fracture sites application of plate and screws to tibia and of iliac bone about both tibia and fibula Note that screws in proximal fragment have broken indicating failure of bone to heal D 8 months after removal of plate and screws and application of iliac bone about fracture sites of tibia and fibula and continuous plaster fixation union established The ankle joint realigned but traumatic arthritis persisted although patient was symptom free and had a good range of ankle motion.

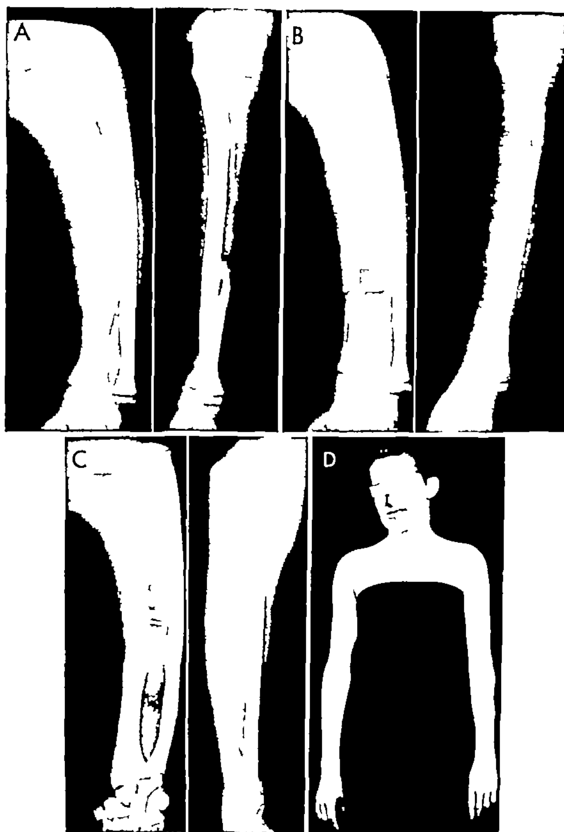


Fig 52.—Open fracture of left radius with extensive bone loss following avulsion of upper two thirds of radius in an 8-year-old boy injured in an automobile accident. A x ray on admission 4 months after injury (See text regarding operation) B fibula transplant 6 months after operation C 7 years after operation continued growth of radius from distal epiphysis some angulation of ulna D 7 years after injury general alignment satisfactory hand function excellent but no supination of forearm although pronation to 60 degrees

by onlay tibial grafts to the radius and ulna and 2 were stabilized by the use of onlay iliac bone secured by screws All united solidly

Of the 3 patients with open fractures one was a boy of 8 who had had the upper two thirds of his radial shaft avulsed in an automobile accident (Fig 52) This fracture was treated by transplantation of a 6-inch section of the fibula The result 7 years later was continued growth of the distal radial epiphysis with reasonably good length to the forearm but marked limitation of supination However there was good return of function of the entire extremity except for limited rotation

The second case was that of a woman of 52 whose forearm was badly mangled in an automobile accident 1 year previously She sustained a severe open fracture of both bones of the forearm (Fig 53) The radius was plated and the ulna wired shortly after the accident Primary healing of the wounds occurred but the bones developed nonunion at one point in the ulna and in two areas of the segmental fracture in the radius Treatment consisted in open reduction through separate incisions internal fixation of the ulna with a Rush pin and the addition of iliac bone The middle fragment of the radius was removed freshened at the bone ends replaced and stabilized with a tibial onlay graft Iliac bone was supplemented The result 1 year after removal of the Rush pin was firm union and a useful extremity but marked limitation of supination



Fig 53 —Nonunion of old open fracture of radius and ulna in a woman aged 52.

NONUNION OF THE HUMERAL SHAFT FRACTURES

Fractures of the humeral shaft are comparable in many ways to those of the femur Nonunion of the humerus is less common however because gravity tends to realign the humerus since the patient is ambulatory Consequently one of the major causes of nonunion in the lower extremity dis-

traction is not present in the humerus Furthermore operative treatment, a common cause of nonunion, has been used less frequently in the humerus than in the femur and tibia When closed reduction of a humeral fracture is not adequate a mass of interposed muscle is usually responsible larger femoral or tibial nails can be used if needed From below it is better to apply the smaller more flexible rods introducing one through each humeral condyle

It should be kept in mind however that the Rush pin does not prevent rotation of one fragment upon the other Conse-

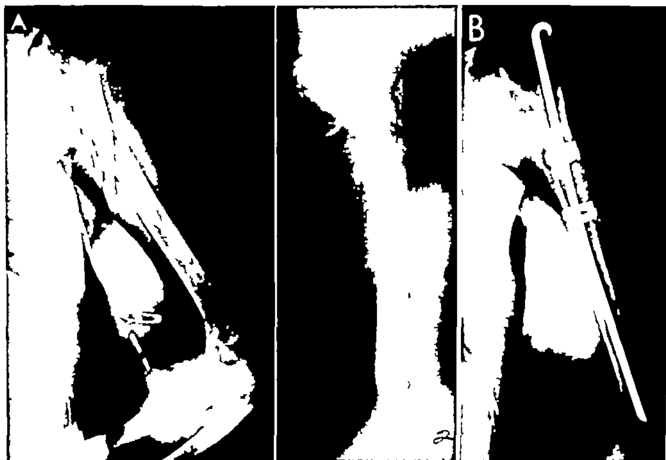


Fig 54 —Nonunion of humerus of 6 months duration in a 46-year-old housewife with multiple sclerosis A, anteroposterior and axillary views 6 months after injury and treatment with external splinting. B 4 months after open reduction insertion of Rush pin and Parham bands and application of iliac bone slabs subperiosteally

quently supplementary internal fixation such as screws placed through one cortex, or Parham bands (Fig 54) may be necessary The preferred grafts are those from the ilium and they can be added in large quantity (Fig 55)

As soon as the situation is recognized open reduction and fixation should be carried out. As with the femur the medullary nail has been the savior for some ununited humeri. By its use stability is increased and joint motion can be initiated earlier

To date the Rush pin has been the most satisfactory type of medullary fixation for the humeral shaft. It is easily inserted either from above through the greater tuberosity or from below through the condyles If it is put in from above one of the

In the humerus external fixation in the form of plaster may also have to be utilized in conjunction with the Rush pin.

Any humeral shaft fracture is easily and safely exposed through Henry's incision. This incision follows the course of the ce-

phalic vein and the entire shaft can be ex posed without danger to any nerve trunks

The physician treating fractures must keep the following points uppermost in his mind

1 The vast majority of fractures will heal if reduced and held sufficiently long by uninterrupted external fixation

2 Improperly executed operations on long-bone fractures account for the in creasing number of cases of nonunion of bone

3 The existence of delayed union is de termined entirely by the x ray film Testing for motion at the fracture site during the healing stage is contraindicated. Immobili zation must be continued

4 Nonunion of bone may be determined by local physical examination as well as by the x ray film

5 When nonunion is established it must in the large majority of cases be surgically corrected

6 Each case of an ununited fracture is a problem unto itself and the operation must be planned accordingly considering the bone involved the soft tissue about the fracture the entire extremity and the pa tient as a whole



Fig 55 —A open markedly comminuted fracture of left humerus (man, aged 57) secondary to bullet (45 cal.) wound 2 years before admission. Open reduction had been attempted but nonunion had resulted. B 6 months after operation to promote union bone healing was accomplished by bone shortening (¾ inch) by stabilization with a Rush pin to prevent angulation and by a plate and screws to prevent rotation at the fracture site In addition a tibial onlay graft was secured with 4 screws and iliac bone chips were added.

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THE ONLAY GRAFT

The onlay graft (Fig 57) may be used for any fracture of any of the long bones when bone loss is not great. The common source of bone for the graft is the tibia. It cised and gently reflected from the tibia sufficiently to obtain a graft without dam aging periosteum and other soft tissue. Improvement in the design of motor drills and saws has simplified the taking of grafts The usual length of the onlay tibial graft

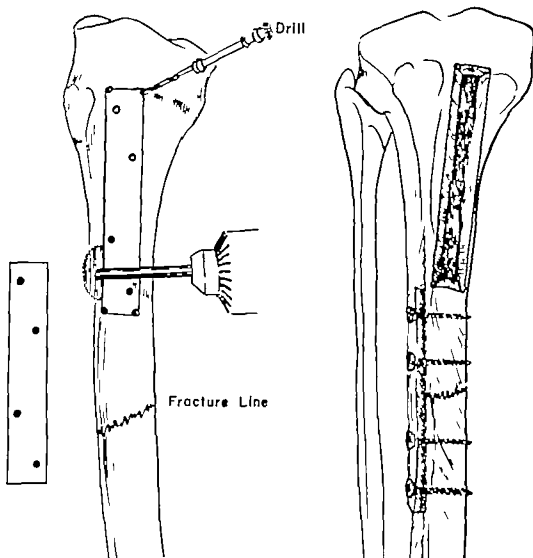


Fig 57 —The onlay graft is removed with a single-bladed motor saw The graft is beveled slightly toward the center Drill holes at the four corners eliminate the possibility of fracture of the tibia Drill holes to accommodate the screws may be made with the graft in situ They are staggered to prevent splitting of the graft.

may be taken from the proximal or at times the distal fragment of the fractured bone depending on the site of the fracture or it may be removed from the opposite tibia. It should be cut with a motor drill (Fig 57) and a motor saw The tibia is exposed with a long curving incision which is carried down to periosteum The periosteum is in- should be from 3 to 4 inches and the width from ⅜ to ½ inch The entire cortex is removed When possible it is better to take the graft from the upper portion of the tibia A single-blade saw is used to outline the graft and a small drill is employed to mobilize the graft s four corners in order to avoid fracture of the shaft of the bone The

motor saw should be used at low speed so as not to burn bone and it is angulated slightly toward the central portion of the bone in order to bevel the graft slightly which also tends to avoid fracture of the surrounding muscles In the tibia it is well to apply the graft to the lateral aspect of the bone Usually the graft is secured by screws which are staggered to prevent splitting the graft and the screws traverse

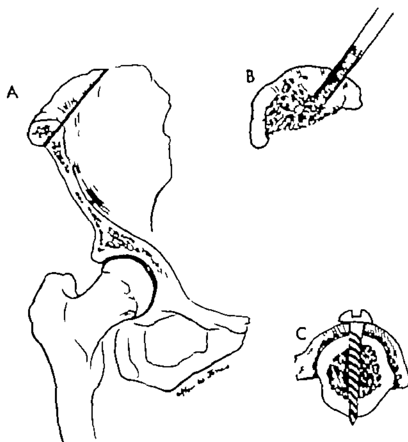


Fig 58 —Massive graft from ilium A, the graft is cut in an oblique manner B cancellous bone is partially removed C the curving iliac crest fits the contour of the bone

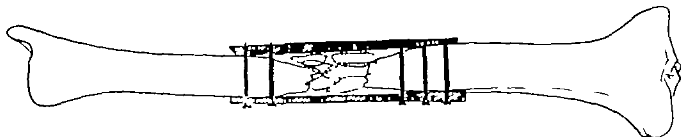


Fig 59 —Double or "twin," onlay graft.

shaft of the tibia. After the graft is cut and while it is still in its bed it is possible to make drill holes in the graft which will ac commodate screws (Fig 57)

The recipient bone is leveled on one side with osteotomes to allow accurate fitting of the graft which is secured to an area of the bone which has the best blood supply from the graft as well as both cortices of the bone to which it is applied It must fit accu rately but must not be placed under stress because stress if present may eventually produce fracture of the graft

Onlay grafts may also be taken from the iliac crest These grafts are particularly useful for application to the radius or ulna (see

Chapter 20 on Fractures of the Forearm) The graft is removed by exposing the anterior and mesial iliac crest subperiosteally on both the inner and outer aspects for a length of about 4 inches and a depth of about 2 inches With a single-blade motor saw or with sharp straight and curved osteotomes the graft is cut obliquely The soft, cancellous bone is gouged out leaving interposed between the two grafts and the ends of the fragments

THE INLAY GRAFT

The inlay graft has been employed in our Clinic very rarely during the last 25 years In our experience it is less effective than the onlay graft, although it is still in favor

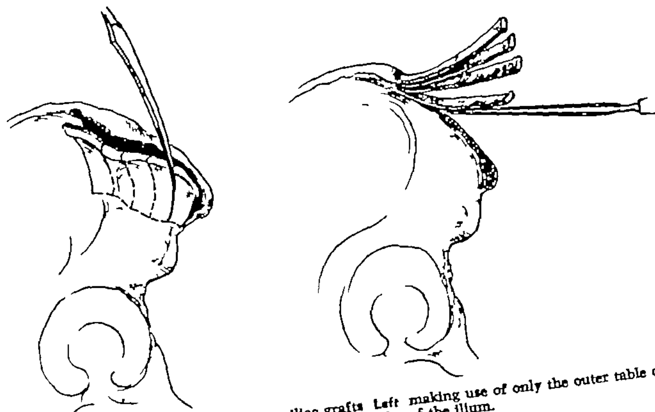


Fig 60 —Technique of removing iliac grafts Left making use of only the outer table of the ilium. Right "horizontal" grafts utilizing both tables of the ilium.

the strong cortex, which will fit the curving contour of the radius or ulna (Fig 58) Four screws are needed to secure the graft to the recipient bone This type of graft is also applicable to the humeral shaft.

Boyd has advocated the use of a double or "twin" onlay graft (Fig 59) particularly in congenital pseudarthrosis of the tibia This type of graft is also applicable in any long bone where there is considerable bone loss and where it is desirable to maintain length This graft is usually removed from the opposite tibia or bank bone may be used but it is well to supplement the double onlay graft with iliac bone chips in some clinics. It may be removed from the proximal or distal fragment, above or below the fracture site The inlay graft may also be removed from the opposite tibia It is cut with a double-bladed motor saw which is also used for making a slot across the fracture line into which the graft is placed Generally internal fixation is not used with this type of graft (Fig 56)

THE SUBPERIOSTEAL ILIAC GRAFT

The subperiosteal iliac graft has been found most useful and it is being employed with increasing favor particularly when

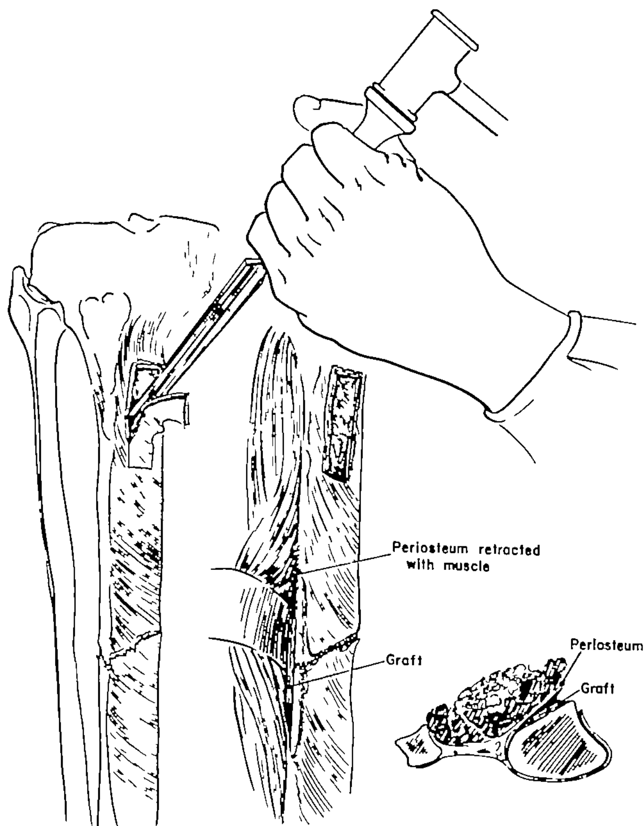


Fig 61 —Osteoperiosteal "neighborhood" graft.

the fracture is in reasonably good alignment and mobilization of the area of nonunion or repositioning of bone fragments is not necessary If realignment is necessary a plate and screws are used to stabilize the bone before inserting the subperiosteal iliac bone around the shaft under the periosteum. For application of this type of graft the bone is exposed subperiosteally with an adequate incision the grafts are removed from the ilium as shown in Figure 60 and are applied to the area of the bone which is most effectively covered by muscle These grafts do not need to be long or very thick and they are placed in a barrel-stave fashion about the fracture site

THE "NEIGHBORHOOD GRAFT"

The osteoperiosteal "neighborhood graft" (Fig. 61) may also serve the same purpose as the subperiosteal iliac graft It is usually removed from the proximal fragment of the shaft, and it is made up of periosteum and a layer of cortical bone thin enough to bend but thick enough to be of value as a source of new bone It is taken as wide as possible from the upper fragment of the bone and placed about the fracture site under periosteum As a rule it is used in conjunction with some form of internal fixation. It may be employed in fresh fractures or in fractures in which operation has of necessity been delayed

THE DOWEL GRAFT

The dowel graft (Fig 62) is employed most frequently in the ununited navicular fracture of or for delayed union in fractures of the femoral neck. For the navicular fracture the graft is usually removed from the tibia with the motor saw For grafting an ununited femoral neck a longitudinal section of the fibula or the entire fibula may be employed In each case the graft is shaped in cylindrical fashion with a rasp When the dowel graft is used in the femoral neck it may be supplemented by internal fixation in the form of a flanged nail, or a combination of nail and plate In the carpal navicular the dowel graft gives stability which is supplemented by external plaster fixation

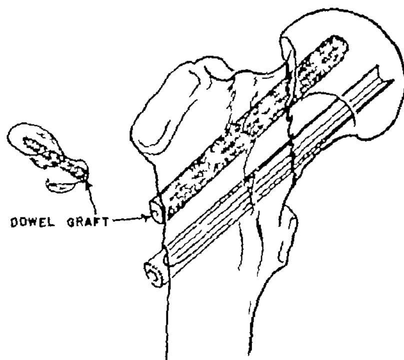


Fig 62 —Dowel graft

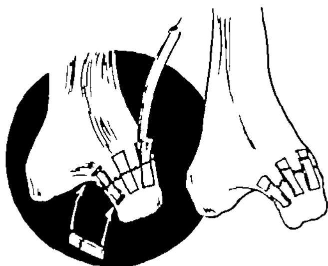


Fig 63 —Slotted grafts are cut with a motor saw turned upon themselves and replaced into the slots

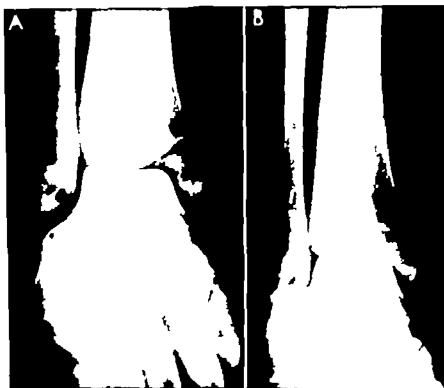


Fig 64 —A, ununited fracture of internal malleolus in 41 year-old guard B bone union which resulted from the use of the slotted graft (see Fig 63)

THE SLOTTED GRAFT

The slotted graft (Fig. 63) has had a limited use in our Clinic. This method of bone grafting has been effective for the un united internal malleolus (Fig 64) and some surgeons prefer it for the carpal navic ular bone

BANK BONE

The use of bank bone has met with mod erate enthusiasm since it was introduced some years ago It is particularly useful when large defects are to be filled but it is generally agreed that heterogenous bone from the bone bank does not act so effec tively for grafting as does autogenous bone and that the hazard of infection is greater

Bone grafts are used primarily as a source of bone to promote healing of a frac ture Albee maintained that the massive bone transplant lived in its new location Opposing this view are others—Leriche and Policard, Groves Gallie Phemister and Ghormley—who believe that the graft dies leaving only the matrix surviving to act as support for newly proliferating osteoblasts which in time completely replace the bone graft. The massive grafts however have considerable value as stabilizing elements but in practically every case they must be supplemented by external fixation in the form of plaster A notable exception is the subperiosteal iliac and tibial grafts used in conjunction with medullary fixation

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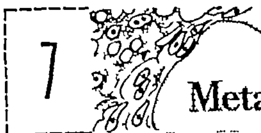
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7 Metabolic Bone Disease

ADULT BONE can be thought of as consisting of a matrix akin to connective tissue into which is deposited a calcium phosphate-carbonate mineral component somewhat similar to apatite * Bone is one of the collagen tissues and it may be involved in some of the collagen diseases but in this chapter the discussion will be limited chiefly to diseases of adult cancellous bone

Bone has tremendous surface area in the human body it is measured in hundreds of acres This surface can be divided into two functional areas (*a*) the area where bone is being formed and (*b*) that where it is being destroyed Whether these two processes occur together or one after the other has not been determined as yet nor as regards the subject at hand, does it matter much In addition bone matrix may occur without calcium—for example in osteomalacia.

BONE FORMATION

Where bone is being formed osteoblasts can be seen laying down osteoid and then becoming entrapped in extracellular substance thus being turned into osteocytes.

The question immediately arises as to how calcium salts can be deposited on certain of the bone surfaces when at the same time they are being resorbed from other surfaces nearby Obviously there must be something different going on at bone forming surfaces from what is happening at bone resorbing surfaces Confronted with such a problem one would naturally look at the bone forming surfaces for factors which might affect the solubility of phosphates of calcium Thus one might look for a localized accumulation of calcium ions or for a localized collection of phosphate ions or one might anticipate a rise in pH

There is considerable evidence that it is the presence of a localized increase of phosphate ions at bone forming surfaces which allows bone salts to be deposited. One finds at these sites the enzyme alkaline phosphatase which has the property of splitting inorganic phosphate off from organic phosphate compounds by hydrolysis

This tempting theory had recently been losing support because apparently there was no store of organic phosphate to be hydrolyzed However it has now been suggested that phosphorylase which is also present where cartilage is being calcified has the property of building up organic phosphate compounds notably glycogen

BONE RESORBING SURFACES

Let us next turn to the second process of bone surface namely the resorption of the bone surface

* Formula: $Ca(OH\text{-}Ca_4(PO_4)_3)_2$.

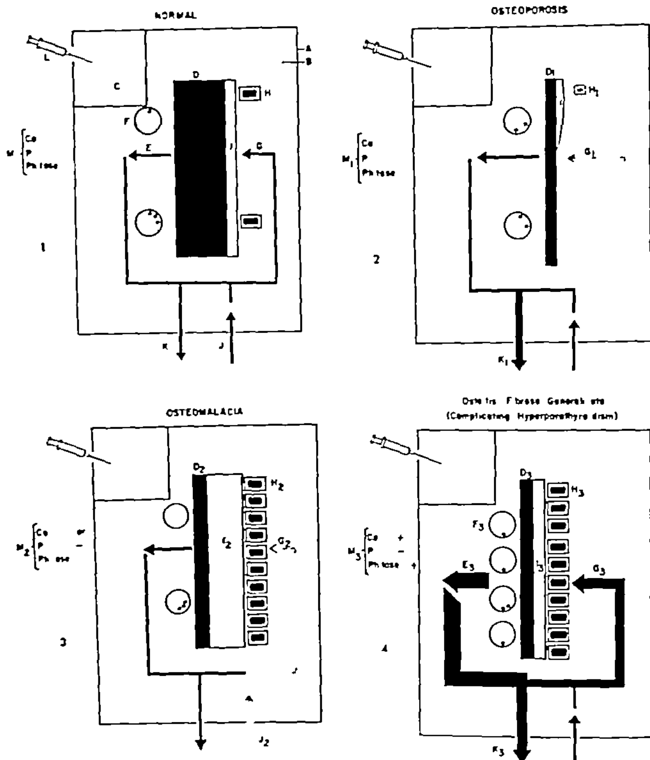


Fig 65 —Schematic diagrams showing conception of differences between normal bone, osteoporosis osteomalacia and hyperparathyroidism with bone disease Key *A* body limits *B* body fluid *C* body serum a compartment of body fluid easy to tap for analysis *D* bone mass with two surfaces—one where bone is being resorbed and one where it is being laid down *E* arrow indicating by its size the rate of calcium and phosphorus resorption *F* osteoclast *G* rate of calcium and phosphorus deposition *H* laying-down of osteoblast *I* osteoid *J* calcium and phosphorus entering body from gastrointestinal tract *K* calcium and phosphorus leaving body by kidney or other exits *L* syringe obtaining serum for analysis *M* blood values (*n* normal + high − low)

Diagram 1 (*Normal*) Note that the calcium and phosphorus going into bone equals that coming out of bone that which comes out goes back in.

To explain the control of bone resorption at the bone resorbing surfaces we may go back to straight stoichiometric inorganic chemistry with its mass laws and solubility products It is believed that bone resorption follows physico-chemical laws and that by kidney control calcium and phosphate and carbonate ions are kept at such levels at bone resorbing surfaces that a fairly con stant rate of dissolution of the bone miner als will take place. Any marked deviation will be self-limited according to the dictates of the solubility product

It is not clear as yet whether the osteoblasts are scavengers which destroy the remnants of the matrix, once the inorganic elements have been dissolved or whether they also take an active part in the removal of the inorganic matter

Just what determines in the first place whether a surface is a bone forming surface or a bone-destroying surface is not at all clear Do the surfaces change often from one type to the other? If so how often?

STRESS AND STRAINS

The structure of the skeleton is constantly changing to meet the stresses and strains to which it is exposed. As had been pointed out above there are two types of bone surface—one for bone formation the other for bone destruction And it appears that bone is constantly being broken down at bone-resorbing surfaces at the same time that it is being laid down at bone-forming surfaces (Fig. 65 Diag *1*) The stimulus for tissue growth is thought to be stresses and strains thus while the skeleton is con stantly being resorbed throughout the body the stimulus for bone formation is restored Bone is put back wherever the stresses and strains are This insures that the construction of the skeleton will always be that best suited to its needs

PARATHYROID HORMONE

Let us now consider the part that the parathyroid hormone plays in the control of the calcium phosphate-ion product at bone-resorbing surfaces

To begin with the stimulus to the para thyroids for increased function is a serum calcium level below 10 mg per 100 cc Increased parathyroid hormone production results in

1 Decreased phosphate resorption from glomerular filtrate
2 Increased urinary phosphate
3 Lowering of serum phosphorus level
4 Decrease of calcium phosphate ion product
5 Increased resorption of calcium phosphate from bone*

* With a high calcium intake the increased absorption of calcium from the gastrointestinal tract would tend to maintain the calcium-phosphate ion product and thus minimize loss of calcium from the bone.

Diagram 2 (*Osteoporosis*) Note decrease in bone mass (D) due to primary hypoplasia of osteoblasts (H_1) with resulting decreased deposition of osteoid (I_1) and decreased calcium and phosphorus deposition (G_1) Note also increased calcium and phosphorus excretion (K_1) because of less calcium being deposited in the bone also note normal blood values (M_1)

Diagram 3 (*Osteomalacia*): Note decreased bone mass (D) resulting from inability of cal cium to be deposited in osteoid tissue (G_s) because of abnormal blood findings (M) with resulting wide osteoid seams (I) and an increased activity of osteoblasts (H_s) The condition is usually due to faulty calcium absorption (J)

Diagram 4 (*Osteitis Fibrosa Cystica Generalisata*) Note increased calcium and phosphorus excretion in urine (K_s) leading to increased bone resorption (E) with an increased number of osteoclasts (F) and resulting in decreased bone mass (D_s) which in turn necessitates increased bone formation with increased number of osteoblasts (H) Even though serum phosphorus is low (M_s) serum calcium is sufficiently high (M) so that calcium can be deposited in newly formed osteoid (I) and calcium deposition is therefore increased

(From Albright, F., and Reifenstein E. C., Jr *The Parathyroid Glands and Metabolic Bone Disease* (Baltimore Williams & Wilkins Company 1948)

6 Increased serum-calcium and serum phosphorus levels
7 Restoration of calcium-phosphate ion product to normal

Thus whereas the parathyroid activity is controlled by the serum-calcium level ("calciostat" of Howard) the parathyroid hormone that is produced exerts its effect through the phosphorus metabolism.

Now let us consider why it is that so many disorders involving calcium privation are found with a serum-calcium level of about 10 mg per 100 cc (normal) and a serum phosphorus level of about 2 0 mg per 100 cc (low as in ordinary rickets renal tubular acidosis and steatorrhea) Is it not because the parathyroid glands are stimulated to action by a serum-calcium level below 10 mg per 100 cc and produce increased amounts of hormone until the calcium level is back to normal?

Note that there are at least two impor *tant* controls for the regulation of the amount of calcium and phosphate which the body fluids can contain (1) the solu bility product and (2) the parathyroid hor mone It is probable that the solubility product exerts a slowly acting widespread influence on the calcium and phosphate ions *while the parathyroid hormone acts as* a fine adjustment.

DISORDERS OF BONE METABOLISM

In a disorder of bones the first thing to be decided is whether the disease is general ized or localized Hormones do not stop at the midline or run down one extremity and not another For example if only one area of abnormal bone is found, the condition is localized it makes no difference whether the disorder is localized to 99 per cent of the skeleton or to 1 per cent

OSTEOPOROSIS

Osteoporosis is characterized by a defi ciency of bone matrix (Fig 65 Diag 2) the matrix that is laid down is calcified and the only abnormality of the bone is that there is too little of it. Osteoporosis is pri marily a disorder of tissue metabolism, not of calcium metabolism

CAUSES OF OSTEOPOROSIS —The causes of osteoporosis are varied and they are linked closely with tissue metabolism There is the postmenopausal condition when the stimulus of estrogen on tissue especially bone tissue is lacking there is the spontaneous Cushing s syndrome when the antianabolic hormone of the adrenal cortex predominates over the anabolic hor mone of the adrenal cortex there is a simi lar man-made condition resulting from the administration of cortisone or cortisone-like steroids there is the alarm reaction of Selye when changes in the adrenal cortical steroid production lead to an over all tissue loss there is old age when atrophy of the osteoblasts and of other tissues under ster oid control takes place Then there are the *deficiencies bone tissue like other tissue* has to be fed Finally there is atrophy of disuse for bone tissue like other tissue requires exercise also to keep from dis-appearing into thin air

TREATMENT OF POSTMENOPAUSAL OSTE OPOROSIS —The question of the proper treatment of postmenopausal osteoporosis is often raised Various factors must be considered In many patients there is some contraindication to treatment such as so-dium retention cardiac failure hyperpara thyroidism or myeloma. Moreover the diagnosis of osteoporosis is difficult to make probably it should not be made in the absence of deformity of the vertebral bodies

If the roentgenograms suggest osteopo-rosis treatment for 3–7 months as a test is indicated Most patients are relieved of back pain in 1–5 weeks In most cases metabolic balances show improvement within 10 days most patients attain positive calcium balances which with continued medica tion may last for weeks or months or years Further deformities do not neces-sarily indicate an advance of the osteo-porosis.

The steroid therapy of postmenopausal osteoporosis can be made very simple. Only

estrogens androgens and progesterones have been widely used None of these has shown any advantage over diethylstilbestrol *

Different steroids stimulate different tissues In postmenopausal osteoporosis where depletion of bone matrix is the primary difficulty estrogens are indicated Such therapy may lead to one difficulty the endometrium may proliferate and become spongy and may finally bleed (metropathia haemorrhagica) This can be circumvented by omitting the estrogen intermittently which results in the casting-off of the endometrium following each episode of estrogen withdrawal Thus overgrowth of the endometrium is prevented Progesterones are used chiefly in conjunction with prolonged estrogen therapy by giving progesterone intermittently "progesterone-withdrawal menstruation" can be induced by correct timing the repeated courses of progesterone can be given in such a way that the intervals between periods will not be sufficiently long to bring about flowing

Testosterone has widespread anabolic functions including an osteogenic component. With its use hirsutism and deepening of the voice must be watched for

In elderly patients with cardiac disease one must avoid excessive salt because of the salt retaining effect of these steroids

With prolonged estrogen therapy vaginal smears should be taken for cytological examination yearly or oftener to aid in the early diagnosis of uterine cancer Whether or not estrogen therapy has any effect on the incidence of uterine cancer is not known.

Osteomalacia

Osteomalacia is a disorder of calcium and phosphorus metabolism wherein there is too little serum calcium for the level of the phosphorus or too little phosphorus for the level of calcium to allow calcium-phosphate salts to be deposited on bone forming surfaces (Fig 65 Diag 3) Consequently these surfaces are covered with uncalcified bone matrix

There is some recent evidence that certain cases of rickets and osteomalacia are due to a primary inability to make phosphatase so that despite normal values for calcium and phosphorus osteoid remains uncalcified This condition has been called "hypophosphatasia"

The rate at which calcium phosphate salts are resorbed from bone-resorbing surfaces depends on the ion product involving the calcium phosphate and carbonate ions The mathematics available for defining the solubility product involved is not simple Furthermore one can envisage the ion product in question being constantly batted about by numerous equilibria affecting it the adsorption of calcium ions onto proteins the linkage of phosphate ions to substances like Amphojel® the binding of calcium and especially magnesium ions to phytate-like substances if such exist the disturbance produced by magnesium ions on calcium ions the effect of diet (notably intakes of calcium phosphorus magnesium) the enzyme phosphorylase the ionization of various compounds etc. the hiding of calcium ions by citric acid and other chelating agents and other conditions affecting ion balance The clinically important factor deduced from all this verbiage is that the product of the serum calcium and the serum phosphorus both expressed in milligrams per hundred centimeters empirically comes as close to paralleling the ion product as would be expected.

Osteitis Fibrosa Cystica Generalisata

Osteitis fibrosa cystica generalisata is the result of a disorder which causes loss of calcium primarily (Fig 65 Diag. 4) The most common cause for this is hyperparathyroidism when the high level of the serum calcium leads to hypercalciuria and this in turn to calcium loss

There are two schools of thought in re

* Diethylstilbestrol is not a steroid but its action on all tissues seems to be similar to that of an estrogen.

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* Diethylstilbestrol is not a steroid but its action on all tissues seems to be similar to that of an estrogen.

gard to the modus operandi of the para thyroid hormone The first and, for the time being, the less popular school envisages (see p 81) the following sequence (*a*) an increase in the hormone (*b*) a decrease in the resorption of phosphate by the kidney tubules (*c*) a fall in the serum phosphorus level, and (*d*) *a fall in the calcium-phos phate ion product at the bone-resorbing surfaces.*

The second school of thought believes that the hormone destroys bone tissue di rectly that this leads to an increase of cal cium and phosphorus entering the blood stream and finally that this increases the serum-calcium level. This school does not explain the cause of the low serum-phosphorus level in hyperparathyroidism Some investigators suggest that there are two parathyroid hormones—one raising the serum calcium the other lowering the serum phosphorus At the present time this theory seems extravagant.

Patients with hyperparathyroidism can be divided into two groups—those with bone disease and those without bone disease Whether or not bone disease will de velop in a patient with hyperparathyroid ism depends on whether the calcium going into the body equals the amount being lost if the amounts are equal, the skeleton will not be encroached on

Paget's Disease (Osteitis Deformans)

Paget s disease varies greatly in regard to the extent to which it affects the skeleton There are all gradations from a single isolated lesion to the case in which the skeleton is almost totally involved The line of demarcation between the involved and the uninvolved areas remains sharp Paget s disease and osteitis fibrosa cystica generalisata have many features in common The primary process in both is bone destruction. This is followed in both by an attempt of the body to repair the damage In Paget s disease this leads to an over growth of badly made bone *In osteitis fibrosa cystica generalisata* it leads to a repair job as orderly and as complete as is possible with the materials available

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8 

Pathological Fractures

A PATHOLOGICAL fracture is a fracture through diseased bone It is obvious therefore that any comprehensive analysis of the problem of pathological fractures would require a complete review of all bone diseases Such a review would be disproportionately lengthy and would serve no useful purpose However certain bone diseases either generalized or localized are so frequently complicated by fracture that they warrant special consideration and emphasis

The following list gives the principal bone diseases likely to be associated with pathological fractures (For details of the derangements in matrix formation and calcification which characterize the various diseases see Chapter 7)

BONE DISEASES ASSOCIATED WITH PATHOLOGICAL FRACTURES

Congenital
- Osteogenesis imperfecta (Fig. 66)

Nutritional.
- Malnutrition
- Burns
- Rickets
- Scurvy (Fig. 67)
- Poliomyelitis
- Circulatory impairment from—
  - a) Aneurysmal pressure
  - b) X radiation fibrosis (e g jaws hips etc)

Hormonal
- Osteomalacia
- Hyperparathyroidism (Fig 68)
- Hyperthyroidism
- Cortisone (Fig 69)

Agnogenic
- Albright s disease
- Bone cysts (Fig. 70)
- Fibrocystic disease (Fig. 71)
- Paget s disease (Figs 72 73)

Neurogenic
- Syringomyelia (Fig 74)
- Charcot s disease

Infections
- Pyogenic osteomyelitis (typhoid)
- Tuberculosis
- Syphilis
- Echinococciasis
- Coccidiosis

Tumors
- (See below p 90)

DIAGNOSIS

It is deplorable that many pathological fractures are unrecognized as such and are treated for long periods as simple fractures without recognition of the presence of the complicating bone disease A high index of suspicion must be maintained at all times A careful history and a complete physical examination will disclose concomitant pathological processes in many instances

Certain data are particularly significant in raising the suspicion of pathological fracture

Fig 66 (left) —Osteogenesis imperfecta Sixteen fractures of femora and marked decalcification of bones in a child of 9 years

Fig 67 (right) —Scurvy Marked displacement of distal femoral epiphyses with rarefied ossification centers and surrounding "white line" in a 9-month-old infant. Massive subperiosteal hemorrhage with beginning calcification



Fig 68 (left) —Bone changes secondary to hyperparathyroidism

Fig 69 (right) —Two views (before treatment and 4 months after treatment) of osteoporosis secondary to steroid therapy Multiple compression fractures of dorsal spine no trauma Patient had bullous pemphigus which was held in remission by 150 mg of cortisone daily for 4 months

HISTORY —Pathological fracture should be suspected when the fracture occurs following trivial or inadequate trauma A history of previous fractures may be volunteered or elicited in certain cases Previous such as pulsation tumor or excessive or absent pain may be elicited

X RAY FINDINGS —Abnormal radiographical appearances either in regard to the type of fracture in relation to the trauma

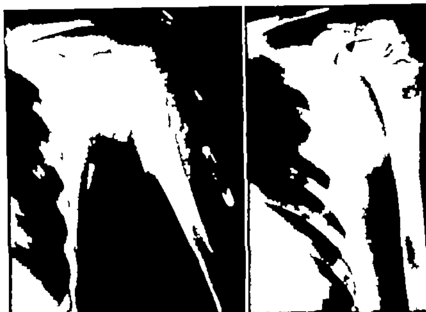


Fig 70 —Multilocular bone cyst Left pathological fracture of proximal third of humerus in a child treated in plaster shoulder spica Right 3 years later obliteration of cystic lesion and healed fracture



Fig 71 —Fibrocystic disease Left two views of spiral fracture through solitary cystic lesion in tibia from minor trauma in a 14-year-old boy Right two views taken 1 year after curettage of cyst and packing with strips of bone-bank rib

or concomitant illnesses may be significant.

PHYSICAL EXAMINATION —Scars of previous operations as for example radical mastectomy or nephrectomy may point to the possibility of metastatic carcinoma. Abnormal findings at the site of fracture

or in regard to the character of the adjacent bone are found frequently A survey of other bones may reveal abnormalities more clearly than does an examination of the area complicated by the fracture Changes in the radiographical appearance during



Fig 72.—Paget's disease Left two views of pathological fracture which occurred in a woman while walking. Right insertion of Küntscher nail made early ambulation possible.



Fig 73.—Paget's disease Left pathological fracture of proximal third of humeral shaft Right treatment by application of hanging cast.

the course of healing are especially important. Delayed and defective healing or abnormal callus formation may be the first indication of underlying bone disease

LABORATORY FINDINGS.—While laboratory studies are helpful in confirming the presence of certain underlying diseases they are usually not carried out unless some suspicion of pathological fracture exists. Urine and blood chemistry studies and serology may all contribute to the elucidation of a diagnostic problem

In summary improved diagnosis of pathological fractures will result from careful study of the patient as a whole with special reference to history and physical



Fig 74 (left) —Syringomyelia Patient had pathological fracture of head and proximal third of humerus after light lifting but did not find it necessary to seek medical aid until 1 week later

Fig 75 (right) —Eosinophilic granuloma The lesion in a 3-year-old child was first noted after minor trauma. Defect has sharply defined irregular border No sclerotic reaction. Biopsy and curettage of lesion with subsequent healing



Fig 76 —Giant-cell tumor of proximal third of humerus **Left** pathological fracture after light lifting by patient. **Right** after curettage and packing with bone-bank chips Complete heal ing 7 years later

examination and with special awareness of the significance of deviations from the nor mal course of uncomplicated fractures

BONE TUMORS

Special consideration must be given to tumors of the bones many of which are first detected or suspected only when a complicating fracture occurs The following list presents the more common tumors which are complicated by fractures

Tumors of Bones

Benign:
- Cysts (dentigerous)
- Eosinophilic granuloma (Fig 75)
- Osteoid osteoma
- Enchondroma
- Fibroma
- Hemangioma
- Lipoma
- Osteochondroma (single and multiple)
- Adamantinoma
- Giant-cell tumor (Fig 76)

Malignant.
- PRIMARY
  - Osteogenic sarcoma (Fig 77)
  - Chondrosarcoma
  - Fibrosarcoma (Fig 78)
  - Ewing s tumor
  - Reticulum-cell sarcoma
  - Hodgkin s disease
- SECONDARY
  1. Direct invasion from adjacent malig nant tumors—e g jaws clavicles sternum, ribs.
  2. Metastases from primary—
     - *a*) Breast (Figs 79 and 80)
     - *b*) Prostate
     - *c*) Hypernephroma
     - *d*) Thyroid
     - *e*) Malignant melanoma (Fig. 81)
     - *f*) Lung
     - *g*) Lymphoma (Fig. 82)
     - *h*) Other sarcomas etc

Diagnosis of Bone Tumors

In many varieties of bone tumor the roentgenograms are characteristic and presumptive roentgen diagnosis proves to be accurate in a large group of cases al though confirmation is essential. For accu rate diagnosis biopsy is necessary in most cases. Aspiration or Silverman needle bi opsy may provide identifiable material for a competent pathologist. In other cases open biopsy is required.

Certain laboratory procedures are helpful in the differential diagnosis of bone tumors Blood studies the ratios of the serum proteins and the albumen globulin marrow biopsy phosphatase determina tions and roentgen examination of the chest and other bones are occasionally helpful.

In diagnosis of metastatic malignant lesions the history of previous operations is especially important Thorough general physical examination with roentgen exam inations may disclose a latent primary focus of disease Here again, it may be necessary to resort to biopsy to establish the identity of the underlying disease

TREATMENT OF PATHOLOGICAL FRACTURES

Basically the treatment of pathological fractures involves the simultaneous treat ment of two conditions—the fracture and the underlying disease An accurate appraisal of the respective gravity of the two will help to determine the emphasis to be placed on the treatment of each

In general the underlying disease must be treated vigorously to provide the opti mum environment for healing the fracture The fracture should be treated by the sim plest means consistent with sound princi ples but the treatment may be modified by the over-all prognosis Thus in advanced metastatic malignant disease the situation may require only palliative and symptomatic treatment, even so far as the fracture is concerned

TREATMENT OF BONE TUMORS

The appropriate treatment of primary bone tumors may be carried out irrespective of the complicating fracture In the treat ment of metastatic malignant lesions com plicated by fracture several agencies are available



Fig 77 (left) —Osteogenic sarcoma with pathological fracture A child aged 14 fell from a bicycle and later had an ache in the knee Immediate high-thigh amputation was performed. Three years later there were widespread metastases

Fig 78 (right) —Fibrosarcoma. Pain in left calf and ankle X ray film showed extensive mottling of tibia with punched-out areas Periosteal reaction and soft-tissue mass with calcification No definite cortical destruction Multiple metastases in chest

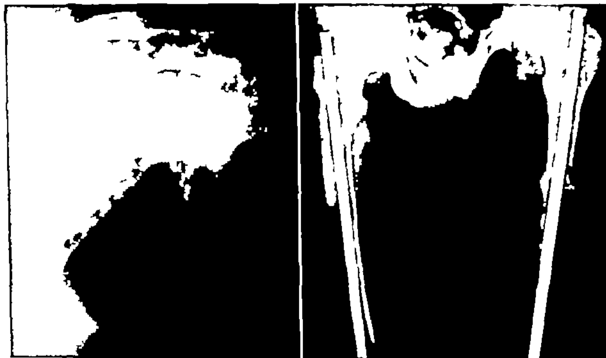


Fig. 79 —*Metastatic cancer of breast advanced multiple lesions* Left pathological fracture of humerus treated with sling Right multiple lesions in femora. Before actual fracture of the bones Küntscher nails were inserted from above through the trochanters without exposing the femoral shafts

FIG 80 (left) —Metastatic breast carcinoma. Rapid osteolysis of middle third of femur Patient was comfortable in Russell type traction until death.

FIG 81 (right) —Two views of metastatic malignant melanoma showing pathological fracture through proximal third of femur after insertion of Küntscher nail patient was comfortable until death, 3 months later



FIG 82.—Malignant lymphoma. Left two views of pathological fracture of distal third of left femur and midshaft of right femur through metastatic areas Right anteroposterior view after open reduction and retrograde introduction of Küntscher nails Patient subsequently comfortable until death 6 months later

Radiation therapy is effective in many types of malignant disease notably reticulum-cell sarcoma lymphoma and Ewing s tumor Radiation in moderate doses may relieve pain due to metastases from various carcinomas In larger doses there is some ground for fear that radiation may interfere with the healing of fractures Although the use of radioactive isotopes is still experimental radioactive phosphorus has been used with some success in the leukemias and other bone-marrow diseases and it appears that radioactive iodine may be of some efficacy in the treatment of metastases from thyroid carcinoma.

Chemotherapy has limited application Urethan offers some temporary benefit in myeloma. Other chemotherapeutic agents such as TEM and TEPA, are occasionally helpful in some of the leukemias and lymphomas The *hormones* are of importance in carcinomas of the breast prostate and gonads and perhaps in a few other types of cancer and in treating metastases from these cancers induced alterations in the hormonal environment have resulted in benefits

Castration in premenopausal women induces regression of breast cancer metastases in many cases Castration in the male is similarly effective in prostatic and mammary cancer Comparable results are sometimes observed following adrenalectomy Hypophysectomy has also been employed experimentally to achieve similar results

The use of androgens and estrogens has been particularly helpful in managing metastases from breast cancer Androgens are used in the premenopausal women and estrogens in the aged women and in males with cancer of the breast and prostate Control of bone pain healing of fractures and reconstitution of bone defects are frequently observed *In lieu* of adrenalectomy cortisone has been proposed and employed to a limited extent with some benefit.

The management of major fractures in cases of malignant disease requires first of all a careful appraisal of the patient s life expectancy and also of the likelihood or possibility of achieving union of the fractures The employment of internal fixation with Küntscher rods is a great boon in controlling pain and facilitating the nursing care of the bedridden patient Simple skin traction may suffice to control pain from a fractured femur or a hanging cast for a humerus Plaster shells may avert collapse of vertebrae and the associated pain and paralysis Radical surgical measures such as laminectomy chordotomy or even amputation may be required solely as palliative measures

MEDICOLEGAL ASPECTS

Nearly every pathological fracture is potentially a medicolegal problem and the physician caring for these patients is frequently called on for testimony as to fact or for expert opinion Court decisions have been variable and often not in accordance with known medical facts

The following three questions deserve exploration and discussion

1 *Did the trauma cause the tumor?*

Since the cause of tumors is not known it is impossible to deny this categorically The best opinion is that a single trauma does not cause carcinoma or sarcoma

Ewing s postulates—that the trauma must be adequate and at the exactly appropriate site and that the time relationship of trauma to tumor appearance be reasonable—must be fulfilled before the possibility of the causal relationship may be entertained.

A possible exception exists in relation to burns Carcinoma may occur with significant frequency in burn scars to justify the assumption of a causal relationship This is true especially in scars that web across a joint and probably it is the repeated trauma, with resultant tearing and fissuring which is responsible rather than any peculiarity of the burn itself Exception may also be made for radiation burns which are known to be precancerous

Repeated or habitual trauma has been implicated as causing malignant neoplasms Carious and jagged teeth seem to determine the location of cancer of the tongue or inside cheek in many instances

The shoe laster who carries a handful of tacks in his mouth may develop a cancerous ulcer at the site. Similar instances do not come to mind in relation to bone disease

Occupational exposure to radioactive material has a definite causal relationship to sarcoma of the bone and there are recorded instances of sarcoma due to external roentgen radiation.

2. *Did the trauma cause the tumor to metastasize?*

The prompt and unthinking answer is in the negative Yet all surgeons base their approach to tumor surgery on the assumption that it is dangerous to cut into a malignant tumor because the disease may spread jeopardizing the possibility of subsequent radical cure Tumor implants in a biopsy wound, or even in a needle tract bear witness to the validity of this assumption. It must be conceded therefore that accidental trauma to a tumor *may* provoke metastasis.

3 *Did the trauma aggravate the condition?*

If trauma may provoke metastasis then it is obvious that an aggravation will have occurred. It may be that the primary tumor itself is aggravated by the trauma, in the sense of growing more rapidly Certainly in some cases of bone sarcoma after fracture the evolution of the bone changes as seen by x ray is almost explosive in its rapidity

The problem of aggravation is a difficult one and offers the lawyers a fertile field for hypothetical questions Since malignant disease is normally fatal and since the course is so variable in duration it is impossible to assert or deny that death or disability has been accelerated by the trauma. Sometimes the trauma draws attention to malignant disease in an operable stage and by bringing prompt treatment to bear may actually be lifesaving. More often a trivial trauma may start the train of symptoms and terminal disability which without the trauma might have been long deferred and postponed In testifying, the surgeon must confine his attention to the case at hand and try to evaluate the significance of the role of the trauma in bringing about the results. Only by testimony based on such honest evaluation can the courts eventually be educated to decide on the justice of claims in this field.

9 

Early Examination and Treatment of the Injured Patient

THIS CHAPTER will discuss the care of the patient from the time he is admitted to the hospital until the time he is sent to the operating room for definitive surgery or to the wards for further observation In the emergency ward examination and treat ment must proceed simultaneously (Table 1 and Fig 83) The purpose of the patient s stay in the emergency ward is to control abnormalities that might be fatal immedi ately to prepare him as adequately as possible for early surgery and to obtain by means of a thorough physical examination, an accurate estimate of his injuries as a base line from which changes in his condi tion can be measured

It is obvious that these same principles apply anywhere an injured person is en countered be it in the street at home or on the battlefield In these areas however usually a minimum amount of care should be given before removal to a hospital The essential measures that may be lifesaving include the maintenance of an airway the control of hemorrhage and the emergency splinting of fractures

When the patient arrives in the hospital he is undressed completely and placed on a Bradford frame or litter by means of which

TABLE 1 —PROGRAM FOR INITIAL EXAMINATION AND TREATMENT

1 Establish an airway Consider laryneal obstruction and tension pneumothorax close sucking chest wounds
2 Control active hemorrhage
3 Treat shock (Fig 83) Give blood for oligemic shock. Suspect cardiac tamponade or tension pneumothorax with chest injuries
4 Splint fractures
5 Examine the patient completely Obtain history Do a neurological examination as indicated
6 Carry out special laboratory examinations Most important are blood, urine and x ray examinations
7 Administer necessary medication including analgesics antibiotics tetanus toxoid or antitoxin and oxygen. Apply dressings to open wounds Patients with serious injuries who are to be operated on must have the stomach emptied and put on constant urinary drainage
8 Establish priority of individual wounds for therapy

he can be transported easily The frame is put on an operating table or truck in the

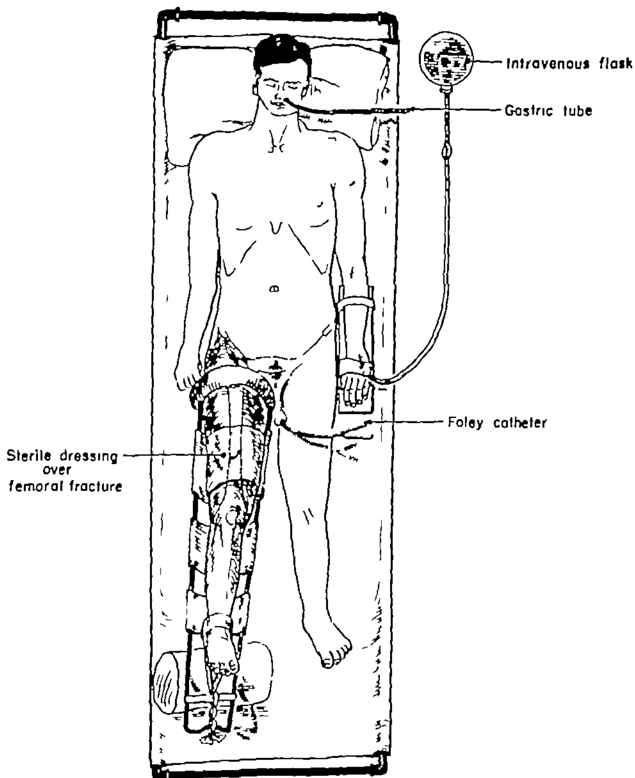


Fig 83 —Preparation of patient for operating room.

emergency ward The surgeon then begins his examination and treatment This will not be a routine leisurely head-to-toe observation It must be rapid and arranged to give precedence to the establishment of proper respiratory function the control of hemorrhage and the treatment of shock Thereafter the fractures are splinted the eign body or inflammatory exudate (3) tracheal obstruction and (4) reduction in pulmonary volume from a traumatic or spontaneous tension pneumothorax or by the lungs filling with water In addition to disordered respiration from mechanical causes the observer must recognize such disorders of rhythm as the Cheyne-Stokes

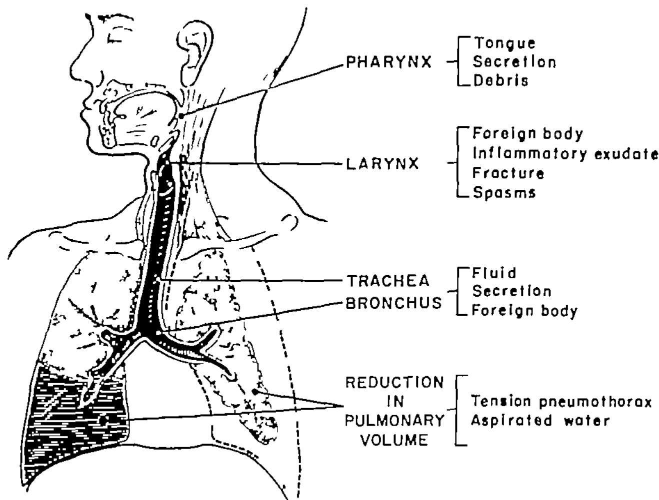


Fig 84 —Important causes of respiratory embarrassment

history and physical examinations are completed and medication and therapy are administered These procedures will now be considered in detail

THE AIRWAY

A sudden interference in respiration may be due to any one of several causes The most important causes (Fig 84) are (1) pharyngeal obstruction caused by excessive secretions or by a relaxed tongue or jaw (2) laryngeal obstruction from a for respiration, the Kussmaul breathing in diabetic acidosis and the characteristically slow labored respirations typical of increased intracranial pressure

When secretions are profuse the use of a suction catheter is necessary A No 14 rubber catheter is passed through the nares and the pharynx is cleared out Often the aspirator can be made to enter the trachea by advancing it through the larynx as the patient inspires Even if this maneuver should fail it may produce a fit of coughing which will open the lower respiratory tree

Insertion of an airway will help keep the tongue forward, although often the mandible must be forced forward to keep the pharynx open

Every emergency ward should be equipped with proper aspirating equipment, instruments for direct laryngoscopy and an assortment of intratracheal tubes. Direct laryngoscopy is the only method by which the larynx can be inspected well and it is the best method to clear the airway The laryngoscopy is most important when the patient is comatose and the cough reflex is lost.

If there are no profuse secretions or if aspiration does not succeed in clearing the respiratory tract, a lower obstruction is present. The larynx is the most common site because of the narrow aperture between the vocal cords In this condition the patient is blue and retraction is visible in the supraclavicular areas and often in the intercostal spaces on every attempt at inspiration. When the stethoscope is used no breath sounds are heard in either lung In a child this is usually due to a foreign body although diphtheritic membranes may be encountered The foreign body may at

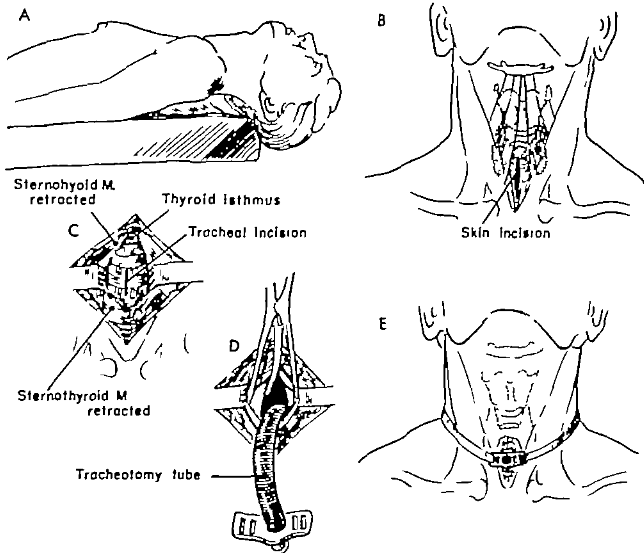


Fig 85 —Emergency tracheotomy A, position of patient with neck hyperextended B vertical skin incision is likely to encounter less bleeding than horizontal C site of tracheal incision. D insertion of special 3-pronged retractor and tracheotomy tube E, final appearance.

times be dislodged by up-ending the child and pounding his back If this fails and direct laryngoscopy cannot be carried out rapidly and skillfully a tracheotomy (Fig 85) is necessary

Tracheotomy is done through the second tracheal ring The neck is slightly hyper extended (Fig 85 *A*) In an emergency no anesthesia need be given although in less pressing instances procaine is used A vertical incision is made (Fig. 85 B) since troublesome bleeding is less likely to be found than if the incision is made on the horizontal plane The incision is carried down immediately to the second tracheal cartilage (Fig 85 *C*) This is opened ade quately When available a tracheotomy tube should be inserted This procedure will be aided by a 3 pronged retractor which holds the trachea open as the tube is slipped in place (Fig 85 *D*)

Tracheal or bronchial obstruction is rarely encountered If present it is nearly always due to secretions since foreign bodies that are small enough to pass be- tween the vocal cords will descend to one of the smaller bronchi.

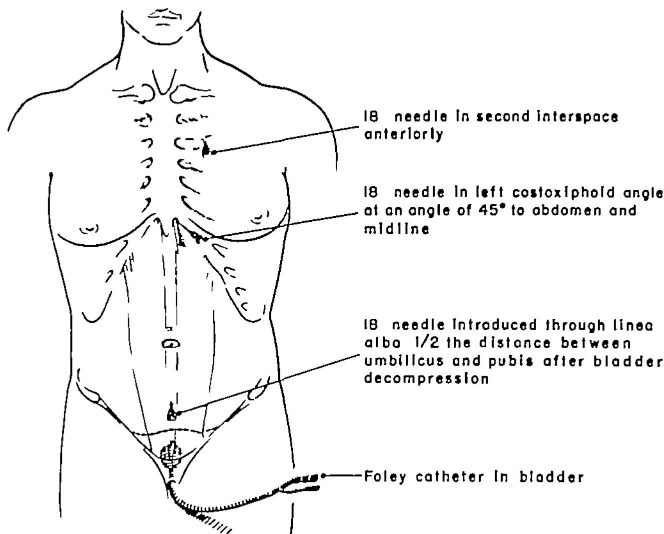


Fig 86 —Sites of important diagnostic taps and methods of tapping the pleural cavity peri cardium peritoneal cavity and bladder

A tension pneumothorax is a very im portant cause of dyspnea. It must be recog nized and treated very rapidly or death may occur It must be suspected in the presence of any chest injury and particularly in the injuries that have caused fractured ribs or subcutaneous emphysema Spontaneous

pneumothorax from ruptured blebs or from unknown causes in young adults is not rare. Whenever tension is increased above the normal intrapleural pressure the opposite lung is compressed. The trachea is deviated away from the side of the pneumothorax, breath sounds are absent and the percussion note is tympanitic on the affected side *If this lesion is suspected, the chest must be tapped immediately before x-rays are taken.*

The chest tap is performed with an ordinary No 18 needle in the second interspace anteriorly (Fig. 86) If air is present under tension it will escape rapidly The needle should be connected to closed underwater drainage placing the tube 10 cm under the level of the water

Another major emergency that produces a dangerous pneumothorax is the open wound of the chest. When the laceration extends into a free pleural cavity air is sucked into the chest with every inspiration Unless the incision can be closed by suture immediately an occlusive pressure dressing is applied which is to be maintained until a definitive operation can be carried out

CONTROL OF EXTERNAL HEMORRHAGE

Hemorrhage is usually venous in type but it may be purely arterial or combined arterial and venous If relatively small or superficial vessels are involved they may be caught with hemostats and tied immediately If this is not feasible the extremity is elevated well above the level of the heart and a pressure dressing applied Venous bleeding will respond immediately If profuse bleeding continues it is better to apply a tourniquet than to grope blindly with hemostats for the involved artery The latter course is justified in an emergency but may damage major vessels beyond repair

If a tourniquet is applied no time must be wasted in preparing the patient for immediate operation The patient should be in the operating room and anesthetized in preparation for removal of the tourniquet no longer than an hour after it was first applied

CONTROL OF MAJOR INTERNAL HEMORRHAGE

Major internal hemorrhage must be recognized promptly There are three important types intra-abdominal intrapleural and intrapericardial Each produces a characteristic set of symptoms *Intra-abdominal hemorrhage* will be considered in detail in Chapter 37 on Management of Abdominal Injuries In brief it may be noted here that such hemorrhage may occur with penetrating trauma or from blunt trauma when the abdominal wall has not been broken. It should be suspected particularly when the lower ribs have been broken on either side producing lacerations of either the spleen or the liver Falling blood pressure rising pulse increasing abdominal or shoulder pain and vomiting are danger signals

Intrapleural hemorrhage severe enough to endanger life is very rarely encountered Major bleeding follows laceration of the intercostal arteries particularly when there are multiple rib fractures It is suspected in the presence of a dull percussion note and absent breath sounds over the affected area, and is confirmed by a thoracentesis. Nearly always the hemorrhage subsides spontaneously and only rarely is an emergency thoracotomy necessary

Intrapericardial hemorrhage on the other hand may be fatal if only a small amount of blood has been lost since if the pericardium is intact, cardiac tamponade will occur It should be suspected whenever there has been penetrating or blunt trauma to the chest. The patient's pulse pressure diminishes Venous pressure becomes high and a paradoxical pulse is noted A paradoxical pulse can be detected by applying the blood pressure tourniquet at the upper level at which the cardiac sounds can just be heard on every inspiration the sounds will disappear The diagnosis is established by a pericardicentesis A No 18 needle is inserted through the left costoxiphoid angle and deviated upward

and medially at an angle of 45 degrees to the abdomen and midline (Fig 86) If blood is found it is aspirated until the motion of the heart can be felt against the needle If the blood should reaccumulate rapidly a thoracotomy may be necessary

SHOCK

Another state that requires immediate treatment is that of shock. "Shock" is a clinical descriptive term referring to a syndrome of low blood pressure high pulse sweating and prostration with diminution in sensorium or loss of consciousness Obviously there are numerous causes for such a situation When a patient is found in this condition in civilian life shock from blood loss (oligemic shock) due either to internal or to external bleeding is by far the most common cause The same syndrome may be produced by an intracranial hemorrhage secondary to cerebral trauma Severe crushing injuries may also lead to it. The possibility of a superimposed heart attack must not be overlooked On the battlefield another common cause of this syndrome is the late abdominal injury in which both loss of blood and the superimposed toxemia of acute infection play important roles

Whatever the cause of the shock emergency treatment must be instituted at once The blood pressure and pulse are taken *and recorded* to be followed by similar observations every 15–30 minutes as required Blood is withdrawn for immediate cross-matching An intravenous injection of 5 per cent dextrose in saline is started If the emergency is great Group O Rh negative blood which has been neutralized by the addition of Witebsky s A and B specific substances may be given without cross matching to be followed by properly typed and cross-matched blood as soon as possible In the Massachusetts General Hospital it is also the practice to screen all Group O Rh negative blood which is to be used as "universal donor" blood to exclude donors with high anti A or anti B antibody titers

The primary treatment of oligemic shock is the administration of blood It should result in prompt improvement in the vital signs If the blood pressure does not rise or the pulse fall while all external bleeding has been controlled one of the other causes of shock must be considered If the patient has received from 500 to 1 000 cc of blood and there has been no response to the therapy the examiner must re-examine the patient to decide which of the usual causes is present The usual causes are

1 Continuing hemorrhage This will probably be an internal hemorrhage from an intra abdominal injury which is the commonest cause of continued shock.

2 An associated cerebral injury or damage to spinal cord

3 A tension pneumothorax, or hemopericardium

4 Massive intraperitoneal contamination from extensive abdominal injuries This produces a shocklike state which is not responsive to blood and which becomes progressively worse as time passes The colon intestine or stomach is the most common site of injury but extensive extravasation of urine or pancreatic enzymes can lead to the same picture

When blood is not available other fluids must be given Five per cent dextrose in saline solution will produce a temporary improvement but the salt soon leaves the blood stream overloading the body with sodium chloride and causing edema. Five per cent dextrose in water is useless Blood plasma will increase the blood volume Freshly pooled plasma is dangerous because of the high incidence of homologous serum jaundice that follows its use However the virus of infectious hepatitis is inactivated if the plasma is allowed to stand at room temperature for 6 months after which time the plasma is safe to use The next best available substitute is one of the plasma expanders Dextran will produce a sustained elevation of blood pressure However large doses of dextran of high molecular weight may produce serious capillary bleeding The reason for this is unknown

The route of administration of these flu

ids is important In the past few years the practice of giving massive intra arterial transfusions in desperate cases has devel oped based on the theory that the coronary arteries are perfused much more rapidly than by the ordinary intravenous route The radial artery is cannulated and the blood injected proximally into the radial artery under pressure *This method is mentioned only to be condemned* In our Hospital gangrene with loss of a hand has occurred in two cases in which it was used, and we have not been convinced that any more is accomplished by this dangerous route than by the ordinary intravenous one

We also believe that it is wise to use the veins of the arms rather than of the legs for these procedures Very ill patients are prone to develop thromboembolism par ticularly when inlying needles are placed in the saphenous system

Other auxiliary measures in the treat ment of shock include the administration of oxygen and the elevation of the lower extremities to provide more blood for the brain The optimum temperature for the patient s welfare is not clear Certainly an unconscious patient should never be placed on any artificial source of heat such as a hot water bottle since serious burns may occur Probably it is best to keep the patient lightly covered and the room temperature at about 70 degrees

SPLINTING OF FRACTURES

During this early examination all obvi ous fractures are splinted The methods for splinting the various fractures will be dis- cussed individually in later chapters

EXAMINATION OF THE PATIENT

As soon as the emergency therapy men tioned above has been completed the sur geon can proceed with a more leisurely but complete examination This will include the history the physical examination and the indicated laboratory studies

The History

As full a history should be obtained as possible The exact manner in which a pa tient fell may give the diagnosis of a frac ture almost as accurately as does the x ray examination. The position in which a per son was hit by a bullet or stabbed with a knife will aid in establishing the tract of the missile or weapon and will indicate whether or not surgical exploration may be necessary Other accurate notations of the time position and principal features of the accident must be obtained for medico- legal details The patient s conduct since the accident is important. If he lost con- sciousness after a lucid interval a subdural hematoma is suggested If he complained of pain or vomited or voided blood since the injury diagnostic leads may be presented.

The Physical Examination

This should follow an expeditious rou tine that will include examination of the following essential points

The Important Vital Signs —These include the level of consciousness the blood pressure the pulse and the respira tory rate These data should be recorded and a chart started

Signs of External Violence.—Any present are noted and described in the record

The Extremities —If the patient is conscious he should be asked to move each extremity in turn Peripheral sensation must be checked carefully Unless this is done particularly when the hand is injured lacerations of nerves will be neglected com- pletely The tests of motion and sensation must cover the entire extremity including the fingers and toes with individual tests of each digital nerve where indicated. Any disturbance of reflexes should be noted

The peripheral arteries should be pal pated. The radial and ulnar arterial pulsa tions at the wrist are particularly important in fracture of the elbow in children. In the foot the posterior tibial and the dorsalis

ırteries must be palpated when there ›acture of the lower femur or about ıee joint A cold white extremity ; injury of the major arteries arterial ıession from hematoma or rarely vasospasm

ıctures should be diagnosed or at suspected at this time Dislocation d be obvious on inspection Deformity tenderness and impairment of func ıre the classic signs of a fracture If a ure is suspected the entire length of ›one must be examined carefully and examination should include the entire

t this time if any fractures are open le dressings are placed on the wounds ractured extremities are then splinted erably in a splint permeable to the x so that no further damage will occur ›re definitive treatment is carried out.

ʜᴇ Hᴇᴀᴅ ᴀɴᴅ Nᴇᴄᴋ —Inspection of the will suggest most of the common frac ›s Fractures of the nasal bones are ac ıpanied by diffuse swelling and often by ıe lateral displacement Crepitus may be lted Depressed fractures of the zygoma demonstrated by comparison of the ıracteristic depression of the malar emi nce with the opposite side Fractures of mandible show varying degrees of de- ›mity usually with malocclusion of the th

Any drainage from the nose or ears must noted. Rhinorrhea is diagnostic of a frac re of the skull into one of the frontal or ›henoid sinuses Bleeding from the ex rnal auditory meatus after trauma to the ad indicates a fracture of the temporal ›ne into the auditory canal

It is next necessary to obtain a rapid es- mate of the damage sustained by the rain The examiner has already noted the ital signs (level of consciousness blood ›ressure pulse and character of the respi ation) A semi or unconscious state an levated blood pressure a slow and full ›ulse or slow and deep respirations indi ›ate major cerebral injuries Inequality or ilatation and fixation of the pupils are seri ›us signs

The cranial nerves must then be tested in order These tests are summarized in Chapter 14 on Craniocerebral Injuries (p 149)

It cannot be emphasized too strongly that this rough neurological examination must be a part of the initial survey and not de ferred for the neurosurgeon who may not arrive on the scene for several hours It is only in this way that the changes in neurological status which may indicate im-mediate surgical intervention can be ap-preciated

A history of "striking bottom when div ing" must make the examiner cautious of a fracture of the cervical spine Extreme care must be displayed in the handling of such patients in order to avoid spinal-cord injury Other neck injuries are uncommon except for suicidal attempts in which vari ous blood vessels are cut where the control of hemorrhage becomes important If a fracture of the cervical spine is suspected the patient should have a Zimmer collar or head traction applied as soon as possible before further motion is carried out

Tʜᴇ Cʜᴇsᴛ —The major injuries that re-quire the most urgent treatment have al-ready been noted the open sucking chest wound, the tension pneumothorax, and car diac tamponade The other abnormalities of the chest which must be watched for on the original examination will just be noted here and then discussed fully in Chapter 36

Inspection of the patient may show re stricted motion of one side of the chest. Subcutaneous emphysema indicative of pulmonary damage may be visible or may be demonstrated on light palpation. Percus sion and auscultation must always be car ried out to determine the presence or ab-sence of pneumothorax or hemothorax. Gentle palpation and localized pain on respiration may indicate rib fractures. In doubtful cases the patient s chest should be compressed between the hands of the sur geon The clavicle and sternum also must be palpated carefully In addition to frac ture of these bones luxation of the sterno-clavicular joint or the costochondral junc

tion may be found In all of these fractures careful physical examination is particularly important because the early x ray picture may be equivocal or negative

If a fractured rib is found it is usually best to splint the chest as soon as the abdomen has been examined either by a tight binder or by adhesive strapping of the affected side in order to reduce the pain and to diminish the chance of further damage to the chest wall.

THE ABDOMEN —Careful observation of the abdomen is especially important in the early appraisal of the patient because in the great majority of cases the diagnosis of visceral injury is impossible immediately after the trauma and becomes apparent only after the passage of a few hours Here a base line must be established immediately The patient must be questioned about abdominal pain vomiting voiding, and defecating after the injury The presence of blood in any of these discharges is especially important The abdomen should be inspected carefully to note any distention The character of the peristalsis should be noted. Percussion may suggest fluid, presumably blood in either lateral gutter Palpation will show any local areas of tenderness The rectal examination must not be neglected The examiner should be concerned particularly with the presence of blood on the glove

THE PELVIS AND BACK —It must not be forgotten that the patient has a back side as well as a front It is a mistake to spend several hours repairing an obvious extensive abdominal wound and then to turn the patient over for the first time to discover irreparable damage to the buttocks rectum and urethra.

Injuries of the spinal cord often produce abdominal pain or are associated with visceral injury It is particularly important in patients with these injuries to test for any disturbance of mobility sensation or reflex changes in the legs

Fractures of the pelvis are usually diagnosed by bimanual compression of the pelvic girdle either laterally or from the front and back In these fractures there is always a possibility of associated trauma to the urethra Any evidence of urinary extravasation in the perineum will confirm the diagnosis

LABORATORY EXAMINATIONS

In nearly every case further special examinations must be carried out before definitive treatment can be accomplished These procedures will be discussed only briefly here

EXAMINATION OF THE BLOOD —The hemoglobin or hematocrit test is the essential part of the blood examination Immediately after a severe hemorrhage the hematocrit reading is normal and it remains so for many hours until hemodilution takes place Unless blood volume studies are carried out the magnitude of the blood loss cannot be estimated. Hence the early hematocrit reading serves chiefly to establish a base line

EXAMINATION OF THE URINE —Urine must be obtained—by catheter if necessary In severely injured patients it is easiest to insert a Foley catheter at once (Fig 86) so that the renal output can be followed accurately Inability to pass the catheter particularly in the presence of a pelvic injury is strong evidence of urethral laceration The urine sediment must be examined for gross and microscopic blood and tested for sugar since a suspected cerebral injury may actually be diabetic coma The instillation of 2 ounces of sterile saline solution into the bladder is often carried out at the same time If the examiner does not obtain a quantitative return of the fluid he injects a laceration of the bladder is probable

DIAGNOSTIC PARACENTESIS (see Fig 86 on p 99) —The examiner may secure confirmation of a diagnosis by tapping the appropriate body cavity Thoracentesis to establish the presence of air or blood in the pleural cavity is the most important procedure Pericardicentesis is necessary occasionally as an emergency measure Abdominal tap may establish the presence of intraperitoneal bleeding.

LUMBAR PUNCTURE — Lumbar puncture may be necessary as an immediate diagnostic or therapeutic measure It is contraindicated when increased intracranial pressure is suspected

SIGMOIDOSCOPY —This procedure is valuable when wounds of the rectum are suspected and it may establish a definite diagnosis

GASTRIC ASPIRATION — Occasionally blood will be found in the stomach after passage of a Levin tube indicating some injury to that organ.

X RAY EXAMINATION —X ray films will be necessary in nearly every injury The examiner should order the proper types of pictures at the outset, so that repeated trips of the patient back and forth to the x ray department will not be necessary There are numerous principles to remember among which the following are the most important

1 X rays for fractures of long bones should include the entire involved bone Anteroposterior and lateral views are essential. Oblique views are often indicated In children, where epiphysial lines are confusing the opposite normal bone should be taken for comparison.

2. The demonstration of skull fractures requires a fairly co-operative patient because of special positions and long exposure Hence this examination should be delayed if the patient is un-co-operative and restless.

3 Fractures particularly of the ribs may be present even though not demonstrated by the early x ray examination A plate taken 10 days later will usually demonstrate callus

4 With chest injuries provision should be made for fluoroscopy at the time of the initial examination

5 When an abdominal injury is suspected plates should be made with the patient both lying and sitting up since only in the latter position can free air under the diaphragm be seen. When looking for free air an upright or lateral position should be maintained for 5–10 minutes before a film is taken.

6 When penetrating wounds from shell fragments or other foreign bodies are encountered all clothing should be removed and the litter should be clean before x rays are taken A laparotomy for a shell fragment that is lying loose on a litter has been done more than once Furthermore when penetrating wounds are encountered be sure the whole anatomical area involved is shown in the x ray The bullet may be located in subcutaneous tissue just off the film

IMMEDIATE THERAPY

The immediate therapeutics of control of hemorrhage and oligemic shock and of obstruction to the airway has been considered but other therapy must be carried out simultaneously with the physical examination or immediately afterward This will include

1 Splinting of fractures as they are encountered

2. Administration of analgesics Morphine or one of its derivatives is usually given to allay apprehension and to relieve pain However there are several contraindications to its routine use If there is a cerebral injury morphine must not be given since it may produce coma and death If necessary to control restlessness pentobarbital sodium is much safer to give When abdominal injuries are suspected morphine will dull the patient s appreciation of increasing pain and will cloud the diagnosis Morphine should be given only to allay severe pain and intravenously rather than subcutaneously to patients who demonstrate signs of shock. If given subcutaneously it will be absorbed poorly After repeated doses a cumulative effect will be noted as circulation improves Morphine poisoning leads to severe respiratory depression.

3 Administration of antibiotics Antibiotics should be given immediately to all patients with open wounds and to those suspected of abdominal or chest injuries A combination of 200 000 units of penicillin and 0 25 Gm of streptomycin should be administered every 3 hours Later a shift

may be made to the appropriate drug de pending on culture and sensitivity tests

4 Administration of tetanus antitoxin or toxoid. Fortunately a high proportion of the younger generation has been immu nized to tetanus and will have had booster doses continued every 3–5 years If such is the case another injection of 0 5 cc of tox old is given at this time if the patient has an open wound If immunization has never been carried out tetanus antitoxin must be given

Because of the high incidence of reaction to tetanus antitoxin it should not be used indiscriminately It is not advised if the wound is superficial and has been acquired under circumstances in which contamina tion with tetanus is extremely unlikely Deep puncture wounds compound frac tures and abdominal injuries in which the intestine has been injured make it neces- sary The usual precautions in the form of an eye or intradermal test must be carried out and extreme care observed when the antitoxin is given to allergic patients The usual adult prophylactic dose is 3 000 units

5 Administration of oxygen. Oxygen should be given to patients with shock or to those showing cyanosis from chest or cere bral injuries Anemic patients do not be come cyanotic so cyanosis cannot be relied on as the only indication for the use of oxygen The most convenient way to give oxygen is through a short plastic nasal catheter at a rate of 6 liters a minute

6 Application of temporary dressings to all wounds No attempt should be made to change dressings until the time has come for definitive surgery

7 Use of urinary catheter An inlying urinary catheter is an essential part of the therapy of any serious injury Only in this way can the total urinary evacuation be checked accurately and oliguria or anuria treated at an early stage

8 Giving of preoperative orders Fre quently the patient goes directly from the accident room to the surgical theater Be fore any general anesthesia is given the patient s stomach must be emptied. This can usually be accomplished by a Levin tube if food had not been ingested immedi ately before the accident otherwise vomit ing must be induced, or a large gastric tube used to lavage the stomach The aspiration of gastric contents can be fatal immedi ately although a late aspiration pneumonia also has a very serious prognosis The dan ger of aspiration is present even though the patient is under local anesthesia and heavy sedation. Consequently care must be taken in every case to avoid this complication

The aspiration of gastric contents is usu- ally inexcusable because it is nearly always due to a lack of awareness on the part of surgeon or anesthetist Every surgeon of experience has heard of such a catastrophe And he knows that it is particularly likely to happen in children since they can retain digested food in the stomach for many hours Therefore the only safe procedure is to be sure that the stomach has been emptied mechanically

Preoperative medication is also neces- sary Atropine is essential, particularly if Pentothal® is to be given Pentobarbital so- dium is superior to morphine unless the patient is in pain. It is well to give atropine or morphine intravenously and to use all sedation sparingly in patients who are to have a general anesthesia.

PRIORITY OF SURGICAL THERAPY

Finally an order of priority for surgical therapy must be established The following considerations will apply to the individual patient with multiple wounds or to a group of casualties with different types of injuries In general the routine to be followed must consider (1) major arterial hemorrhage and (2) severe interference with the airway (these conditions have the highest priority sucking chest wounds are closed at once) (3) abdominal injuries (4) major arterial injuries in which restoration of the circu- lation is feasible by suture or graft (5) compound fractures (6) chest injuries and (7) head injuries When the chest and abdomen are injured simultaneously as by

a missile that penetrates the diaphragm it is best to explore the chest first so that the diaphragm can be sutured and the pulmonary function stabilized

When the initial diagnosis and therapy are completed the patient is sent either to the operating rooms for definitive surgery or to the wards for further observation In either case a complete record of the initial examination must accompany him



10 Use and Abuse of X-rays in Fractures

HISTORY

ON THE EVENING of November 8 1895 Professor Wilhelm Conrad Röntgen of Würzburg Germany while working in his darkened laboratory experimenting with a cathode-ray tube observed that some crystals lying on a nearby table fluoresced That moment marked the transition point between old and new methods in the diagnosis and treatment of fractures Röntgen pursued his observations and found that the crystals gave off visible light, even though the tube was completely covered and emitted no visible light. He was intensely interested in his discovery and developed it thoroughly publishing his results on December 28 1895 In this paper he described the first photographs of the bones of the hand of a living person He gave to these rays the name of "x" or unknown rays Subsequently the medical profession honored Röntgen by naming them "roentgen rays"

Dissemination of this discovery took place with phenomenal rapidity and during the ensuing year 1896 over 1 000 scientific articles and books as well as countless newspaper and magazine articles appeared Owing to the excellence of Röntgen s presentation the method came into practical use almost simultaneously throughout the civilized world

As was to be expected this new discovery was accepted with enthusiastic acclaim by some was observed with doubt or completely ignored by the great majority and was actively opposed by a few reactionaries One of the first to recognize the importance of this new discovery was a Boston surgeon M W Richardson of the Massachusetts General Hospital who stated in 1896 that henceforth no hospital could be considered well equipped unless it had a complete x ray unit. Other equally famous men however failed to understand or accept the value of the x ray in its early presentation

During the first few years of its use the x or roentgen ray revolutionized the practice of medicine Its first and most obvious use was in connection with orthopaedic surgery in the diagnosis and management of fractures and the removal of opaque foreign bodies Before this epoch making discovery the diagnosis of fractures was made entirely by physical examination and of necessity fissure or greenstick fractures and fractures without displacement often passed undetected Medicine as a whole was quick to recognize the value of this new method in determining the pres-

ence or absence of a fracture and it was soon found that the only adequate way to detect and study such injuries was by a series of radiograms

From this beginning radiology grew rapidly aided by the impetus of two world wars Initially the apparatus was crude fluoroscopy was employed extensively and radiograms were made on glass plates In 1914 the plates were replaced by films which came into general use about 1919–20 Originally films were of an inflammable nitrate base In 1924 cellulose acetate was introduced to reduce the danger from fire but the use of nitrate base films did not cease until 1934

Since the close of World War II there has been an increase in the use of x ray in all branches of medicine During this period fluoroscopy although extending its usefulness in certain fields of medicine gradually fell into disuse in the reduction of fractures In both world wars the necessity for locating foreign bodies was of major importance but with the return of peace after each conflict such studies relapsed into minor significance

The changing practice of radiology through these various eras can be related partly to changes and improvements in apparatus which permitted the taking of films in a short space of time thus eliminating the necessity of fluoroscopy in many instances Furthermore a growing consciousness of the dangers inherent in fluoroscopy to both the patient and the physician developed Some of the increasing demand for roentgenography stems directly from the education of the public which took place when large segments of the population were introduced to modern medicine for the first time in the Armed Forces

LEGAL PROBLEMS

With the advent of the x ray medicolegal problems increased and became more complex As early as April 1895 in Denver Colorado a case was tried in which x rays were used as evidence Later in 1910 the first instance of a physician being sued for failure to employ the x ray diagnostically occurred In this instance the surgeon had examined an injured extremity by means of a fluoroscope and had made a diagnosis of sprain Later the patient was found to have had a fracture and a suit was brought the plaintiff contending that there had been negligence on the part of the surgeon in his failure to take an x ray photograph in addition to examining the limb by the fluoroscope This early case was decided in favor of the surgeon but since that time courts have held with almost complete unanimity the reverse of this verdict—namely that an x ray photograph or radiograph is an essential part of the diagnosis and treatment of fractures There have been occasional verdicts to the effect that if a fracture can be properly diagnosed without the use of x ray no negligence is to be inferred from the failure to obtain radiographs but in practice today it has become virtually mandatory for the attending physician to obtain adequate radiographs in any case in which a fracture may have been suspected From a strictly legal point of view it is apparent that the physician who believes himself competent to diagnose a fracture without the aid of an x ray may do so However in the face of the majority opinion, as expressed by a large number of court decisions throughout the entire country the individual who neglects to obtain a radiograph is taking a distinct chance

It is not enough simply to obtain radiographs in a case of suspected fracture these radiographs must be of adequate quality and sufficient in number Judgments have been obtained by plaintiffs in instances in which no films were secured after there had been possible slipping of a fracture following reduction. Today it is a well-established procedure to obtain films of the affected part after reduction and the application of immobilizing devices Some court rulings have gone so far as to state that not only one x ray picture but two a front and side view should be obtained and that further radiographs should be taken after the fracture has been set to make sure that alignment is maintained It

is noteworthy that over half of the judg ments won by plaintiffs in suits over diag nostic roentgenology have centered around the problem of fractures

To summarize the question of the necessity of obtaining adequate radiographs in a case in which fracture is suspected it may be stated that failure to secure radiographic evidence does not necessarily provide con clusive evidence of neglect However the physician who is armed with satisfactory roentgenograms is in a position to defend himself better than one who must rely on less concrete evidence

The second major legal problem arising from the use of x rays in the management of fractures is that of skin damage or burns produced by injudicious use of the roentgen rays Occasionally especially in the early days of x rays severe burns have been produced by the taking of radiographs par ticularly when the operator has been un skilled. In the majority of cases burns have occurred as a result of the fluoroscopic observation of a fracture primarily used in reducing the fracture In such instances many verdicts have been rendered in favor of plaintiffs so that the inherent danger of fluoroscopy to the patient as well as to the radiologist and surgeon must be empha sized.

ROENTGENOLOGY & FLUOROSCOPY IN TREATING FRACTURES TODAY

The original x ray machines were capa ble of producing only small amounts of x ray energy This fact explains the use in the early days of the fluorescent screen by which the examiner could observe a fracture The surgeon could see a gross major fracture manipulate it and observe it after it had been set in a very short period of time whereas if he were compelled to wait for the taking of glass plates many minutes would be required for each individual exposure It was from these early investigators that the most important lessons concerning the dangers inherent in all exposure to x rays have been learned Many of these pioneers unwittingly sacrificed their hands and even their lives to the new discovery and in doing so they tragically demonstrated the damaging effects of prolonged exposure to x radiation

At the present time there is a definite trend away from the use of fluoroscopy in the diagnosis and management of fractures at the Massachusetts General Hospital it has virtually ceased Legally as noted above it has been held that fluoroscopic observation may be inadequate to exclude the presence of a fracture In prac tice as well, most radiologists have learned that fluoroscopy is a most inadequate substitute for proper radiograms The value of a radiogram as a medicolegal protective device is evident

Far more important however is the dan ger to which the physician subjects his patients and himself if he customarily em ploys fluoroscopy in the diagnosis and treatment of fractures Any radiologist or surgeon doing a reasonable amount of this work is almost certain to receive more than the accepted "permissible amount" of radi ation. It is impossible to predict from any mathematical formula the exact amount of radiation which a particular fluoroscopic apparatus will deliver to a patient. It can be stated however that with good ma chines operating under proper conditions, and with a kilovoltage of not more than 85 a milliamperage of 4 or less at least 1 mm (and up to 5 mm.) of aluminum filtration and a distance between the x-ray tube and the surface of the patient s skin and the examiner s hand of at least 14 (and prefer ably 18) inches somewhere in the neighborhood of 7–20 roentgens per minute will be delivered to the skin As little as 150–200 roentgens of this type of radiation may produce an erythema or reddening of the skin and this in turn indicates that permanent skin damage has been done Years later such skin may show atrophy telangiectasis and even the formation of late carcinoma. A dosage of 600 roentgens will cause damage to growing epiphyses in a high per centage of cases while 1 200 roentgens will stop all growth in unfused epiphyses Thus it is clear that as little as 8 minutes of this

type of fluoroscopy may produce permanent skin damage to the patient while greater amounts are likely to cause damage to growing epiphyses

It must be emphasized further that these results produced under ideal situations may be greatly magnified in a far shorter period of time if the x ray equipment is outmoded and out of repair If the distance between the x ray tube and the patient is reduced the amount of radiation striking the patient will increase greatly this effect being governed by the inverse square law As an example if the distance is reduced from 20 to 10 inches the amount of radiation delivered to the skin will be increased by a factor of not 2 but 4 Particularly to be condemned in this respect is the head fluoroscope an apparatus which can be worn enclosing the eyes in a light tight box with a fluorescent screen at one end This type of device is apt to be used at extremely short distances from an x ray tube and in one instance it was found that a dose of 400 roentgens per minute was delivered to the region of the fluoroscopic manipulation

Filtration of the primary x ray beam is of utmost importance in fluoroscopy and in radiology A minimum of 1 mm of aluminum additional filtration should be used under all circumstances and it has been found that as much as 3–5 mm does not appreciably reduce the amount of x ray which is valuable for diagnostic purposes while removing much of the undesirable or soft radiation

Whenever an x ray tube has to be changed replaced or repaired it is most important that the aluminum filtration be replaced in the aperture of the tube and the tube output recalibrated The amount of x ray produced by an individual machine for fluoroscopy or for radiography should be determined and such measurements should be carried out at regular intervals if the maximum protection is to be provided. This determination can be made only by a properly trained physicist or radiologist.



Fig 87 —Radiation necrosis and dermatitis Hands of a hospital technician who served as an orderly for 10 years helping to reduce fractures under fluoroscopic observation Multiple operations with removal of several fingers were ultimately required (Courtesy of Dr E M Daland)

Protective devices in the form of lead rubber aprons and gloves are commonly utilized to guard against the dangers of radiation They are intended solely as pro-

tection from scattered rays which have been produced by the primary x ray beam s striking the table top the patient or some other object they are totally inadequate to exclude the primary beam itself and should never be counted on as protection against it. The wearing of such accouterments especially lead rubber gloves makes accurate manipulation of a fracture extremely difficult If however a surgeon insists on manipulating fractures under fluoroscopic control he as well as the radiologist should protect himself not only with lead rubber gloves but with a full length lead rubber apron of proper thickness If he cannot protect his hands with lead rubber gloves while doing the necessary maneuvers he must at all times refrain from placing them in the direct beam of radiation

There is one field in the management of trauma in which the use of fluoroscopy is perhaps necessary and that is the accurate localization of opaque foreign bodies A foreign body is usually detected first by roentgenography films being taken in planes at right angles to one another When the metallic object has been localized as well as possible by this means the radiologist and surgeon in co-operation should observe it under the fluoroscope The skin point which is nearest the metal is then determined by rotating the part in question Actual removal of the foreign body may be accomplished by the insertion of metal needles close to the object using brief fluoroscopic observation. This method is satisfactory for small parts of the body but not for deep-seated objects

In contrast to the dangers which exist in fluoroscopy roentgenography can be done without risk to the physician and with little if any risk to the patient The visualization of fine details which is impossible by fluoroscopy is well accomplished with radiograms In most instances a considerable number of films may be taken without exposing the patient to any appreciable danger Roentgenograms taken after correction of the fracture and application of an immobilization device serve as a permanent record to evaluate the progress of healing. It is a well known fact that during the application of a plaster casing a fracture which may have been well reduced can slip Without the evidence of a postreduction roentgenogram the final result of the procedure cannot be assured

Until comparatively recently concern over radiation danger has been limited to two main points (1) damage to skin and local tissues such as the epiphyses cornea etc and (2) damage to the hematopoietic system resulting in anemia leukopenia or leukemia In the majority of cases these changes have been found in those working with roentgen rays—namely radiologists orthopaedists and technicians Lately greater emphasis has been placed on the possibility that genetic effects may be induced by radioactivity including diagnostic roentgenology Although there is no positive evidence that this danger is more than theoretical at the present time it is certainly important that the roentgen ray be used as judiciously as possible in arriving at adequate diagnoses This is particularly true in examining the lumbar spine pelvis and hips of individuals in the reproductive years Every protective means should be employed to shield the gonads as much as possible

The general principles of roentgenography which should be observed are

1 The x ray machine should be of adequate capacity to permit the taking of films in a short space of time The machine should utilize a rotating anode tube which allows the use of a much smaller focal spot than was possible in the past

2. The part to be examined must be as close to the film as is possible

3 The part to be examined must be immobilized using sandbags and compression devices The patient should be made as comfortable as possible to avoid any motion during exposure In this connection it is important to emphasize that a patient who is disoriented or in pain cannot co-operate adequately and under these circumstances good films cannot be obtained

Except in a real emergency x ray examina tion should be postponed until the patient is in a more favorable condition

4 The roentgen ray should be filtered by at least 1 mm and possibly up to 5 mm of added aluminum filtration The beam should be confined by a cone or diaphragm preferably rectangular to the area of inter est radiating as small a portion of the pa tient s body as is practicable

5 Darkroom facilities should be of the best quality providing absolute exclusion of white light during the processing of films This is as important as all the pre-ceding factors regarding x ray technique To give the best results the chemicals must be in good condition and maintained at proper temperature After processing films should be completely dried before they are viewed except in emergencies when they may be briefly examined and then returned to complete the processing cycle

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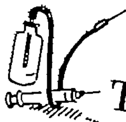
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11 Traumatic Shock

SHOCK, a complicated state of failing circulation is a primary disease state with which every physician and surgeon has to deal. An understanding of its pathogenesis and of the fundamentals of treatment is as essential to a physician's learning as is knowledge regarding the specific bacteria causing infections The physician needs to know the variable facets in detail in order to anticipate events for the prevention of shock is always more economical than its relief once established Organs suffer during shock—the longer the duration, the more problematical the treatment and doubtful the outcome

The unfolding of our knowledge of traumatic shock has come slowly Only as medical science has developed has the pathological physiology of shock been clarified and treatment organized The history of the unfolding is instructive because it shows the development of ideas and how research is an essential preliminary to sound therapy The presentation of shock in this chapter therefore is from the historical point of view

DEFINITION AND DESCRIPTION

Traumatic shock is a state in which failure of the circulation is either impending or established Organ function is threatened Life hangs in the balance and if therapy is not prompt and adequate life ceases The term "shock" is applied to the range of the clinical states from impending failure to death.

Shock has been variously classified as primary and secondary and according to the initiating causes These classifications historically have helped in the definition, but an elaborate system is no longer needed "Primary shock" is well retained to cover the neurocirculatory collapse occurring without blood loss "Secondary shock" covers the shock due to blood loss and to infectious toxemia, and is too broad to have much meaning beyond "traumatic shock" itself Only burn shock will be separately described because of the specific mechanism leading to a reduced blood volume (see Chapter 42 Burns) The nineteenth century provided many accurate descriptions of the clinical picture of shock. John Collins Warren Professor of Surgery at the Harvard Medical School and Visiting Surgeon of the Massachusetts General Hospital gave this interesting account in 1895:

A patient is brought into the hospital with a compound comminuted fracture or with a dislocation of the hip-joint added to other injuries where the bleeding has been slight. As the litter is gently deposited on the floor he makes no effort to move or look about him He lies staring at the surgeon with an expression of complete indifference as to his condition There is no movement of the muscles of the face the eyes which are deeply sunken in

their sockets have a weird uncanny look The features are pinched and the face shrunken A cold clammy sweat exudes from the pores of the skin which has an appearance of profound anemia The lips are bloodless and the fingers and nails are blue The pulse is almost imperceptible a weak thread like stream may however be detected in the radial artery The thermometer placed in the rectum (it would be useless to attempt to take the temperature in the axilla) registers 98 or 97 F The muscles are not paralyzed anywhere but the patient seems disinclined to make any muscular effort. Even respiratory movements seem for the time to be reduced to a minimum Occasionally the patient may feebly throw about one of his limbs and give vent to a hoarse weak groan There is no insensibility (coma is not observed in cases of shock) but he is strangely apathetic and seems to realize but imperfectly the full meaning of the questions put to him It is of no use to attempt an operation until appropriate remedies have brought about a reaction The pulse however does not respond it grows feebler and finally disappears and "this momentary pause in the act of Death" is soon followed by the grim reality A post mortem examination reveals no visible changes in the internal organs

This patient, we now know was in advanced shock. We also can presume that there had been hemorrhage from the site of compounding immediately after the injury although Dr Warren saw inadequate evidence of it on the clothing The description is typical of many other accounts of the period when clinicians were starting to define and classify shock. Experimental science was not yet a part of the learning of the clinician and progress depended on description.

PATHOLOGICAL PHYSIOLOGY

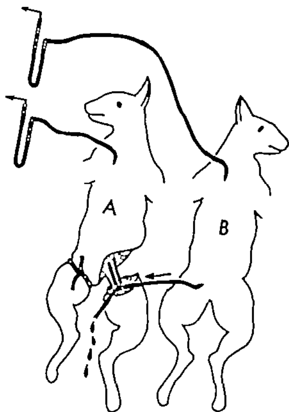
The years of World War I saw the first organized understanding of traumatic shock. Prior to those years shock had been the province of the surgeon and he had done little but describe it. Teams of British and American physiologists during World War I both in France and in civilian laboratories critically examined and experimentally investigated the problems of shock, laying the basis for our modern concepts The teams included Bayliss Dale Cannon Aub and Erlanger Many of the investigations are recounted by Cannon in his classic monograph on *Traumatic Shock* published in 1923

In the 20-year period between the two world wars progress in the understanding of shock continued but at a slower pace However knowledge in related fields of medical science important to shock advanced rapidly The advent of World War II provided a new impetus and investigations in shock utilized the knowledge already gained in such fields as protein chemistry and bacteriology The concept of hemorrhage and loss of effective blood volume bacterial wound infection and the consequence of delay in therapy were confirmed as the salient etiological features The less common aspects and the more significant complications were more clearly defined Although there is still much to learn an effective therapy has emerged

NEUROGENIC CONCEPT

The first physiological concept to be suggested as a cause of shock was the disorganization of the nervous control of the blood vessels In their analysis of wound shock during the Civil War Mitchell Moorehouse and Keene suggested that shock was a reflex paralysis of some vital nerve center or the vasomotor nerves At the turn of the century Crile conceived that shock was due to vasomotor exhaustion His concept received wide support from a clinical point of view it seemed altogether reasonable since blows to a number of places in the body resulted in collapse without outward signs of hemorrhage After all fainting was an obvious example of transient vasomotor collapse or shock.

Research during World War I and again during World War II failed to substantiate neurocirculatory collapse or vasomotor exhaustion as a principal cause of shock. Only the initial fainting due to pain or excitement the tourniquet reaction a blow to the jaw or celiac plexis and direct trauma to the head with brain injury remain as accepted examples of neurogenic shock. (See p 122 on Trauma to Specific Body Areas)



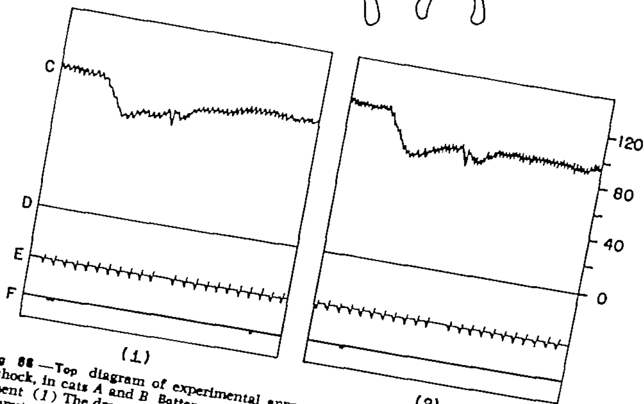


Fig 88 —*Top* diagram of experimental approach producing tourniquet and neurogenic reflex shock, in cats *A* and *B* *Bottom* tracings of two sections of a kymographic record of the experiment (*1*) The drop in blood pressure of cat *A* following arterial perfusion (from cat *B*) of its amputated left leg. (*2*) The drop in blood pressure subsequently obtained in the same animal from the application and release of a tourniquet on the right leg. Period of obstruction of circulation was the same in both instances *C* systolic blood pressure *D* blood pressure base-line *E* timer in 5 seconds *F* marker (*1*) Opening and closing of perfusion (*2*) release of tourniquet

On present evidence there can be no doubt however that the autonomic nervous system through its control of the peripheral blood vessels and blood flow commonly plays a role in the compensation to shock Abundant experiments indicate that a principal reaction of the body to hemorrhage with a falling blood volume is a vasoconstriction of the arteries to certain areas of the body with shunting of the remaining blood on the basis of a new priority to the more essential organs Thus the blood flow to the entire splanchnic area is diminished or nearly shut off when the blood pressure of an animal is threatened by hemorrhage while blood flow to the brain is maintained The ashen pallor and sweating of the skin of the patient in impending shock is clinical substantiation of the vasoconstriction carried out by the autonomic nervous system The extent of the shunting effected and the priorities for the remaining blood are still not exactly known

The autonomic nervous system plays an additional compensatory role through control of cardiac rate and perhaps by increase in tone of certain veins In the so-called "irreversible state of shock" (see p 118 on *Blood Loss*) *a decreased blood flow with* oxygen lack during the phase of developing shock may result in final failure of the vasomotor centers and reflexes with more generalized collapse The experimental evidence in this regard is still uncertain

The tourniquet reaction the fall in systemic blood pressure which follows the release of a tourniquet is also an example of a peripherally induced vasomotor collapse which may be a contributing cause of shock in some patients and should be prepared for when a tourniquet has been on a limb for more than 5 minutes The tourniquet reaction is described below under Blood Loss

Cardiac Failure as a Cause

At the time of World War I heart failure was considered as a source of shock Therapy such as camphor and digitalis was often directed at the heart Today there is no evidence that the heart of a healthy individual is the causative factor in traumatic shock except when the heart is directly damaged Indeed the normal heart of a previously healthy individual stands up remarkably well under the falling blood volume and falling circulation

Restoration of the blood volume by transfusion or other colloid fluid is immediately followed by prompt return of the blood pressure It is only after prolonged shock that the blood pressure may not return to normal and it has not been conclusively shown that this is due to cardiac failure rather than to failure of peripheral arteriolar constriction

Cardiac standstill may be induced by a severe direct blow to the chest over the heart The consequence of such a blow and of direct injury of the heart by crushing or penetrating trauma will be referred to below under Trauma to Specific Body Areas An electric current may also bring about immediate cardiac arrest. Obviously also in a patient with pre-existing heart disease the additional burden placed on the heart of trying to maintain a blood pressure in the face of a falling volume may induce a *more serious cardiac accident* The possibility of such an accident must be considered particularly in patients in the later decades of life

Blood Loss

There can be little doubt that loss of an effective blood volume is the most significant factor in shock and hemorrhage the most frequent cause * In this generation when the factor of blood loss is so well understood it is surprising to look back and realize that it was really not appreciated until World War I Undoubtedly the reason why this factor was not appreciated was the frequent lack of impressive evidence of external hemorrhage on the clothing of the patient with a compound fracture of the leg or other injury The surgeon had also been thrown off guard by a

* The mechanism in burn shock is described in Chapter 4, on Burns

normal hemoglobin concentration not realizing that this laboratory measurement was consistent with recent hemorrhage

The investigations of the shock teams during World War I were both experimental and clinical. The effects of hemorrhage and a variety of therapies were extensively explored in experimental animals First it was established that the blood pressure of an animal would be spontaneously restored if the hemorrhage were limited but that the withdrawal of further blood could no longer be compensated for and the blood pressure would remain low In such a phase it was found that physiological sodium chloride solution would raise the pressure to normal but only transiently A colloid solution such as that of gum acacia was needed for sustained restoration of the blood pressure As a result of these experiments the intravenous injection of gum acacia rather than simple salt solution was introduced in the treatment of war casualties and the first thought of blood transfusion appeared

Clinical observations were carried out on the wounded For the first time actual measurements of the circulating blood volume were made Keith introduced the technique of a vital dye to measure the circulating plasma volume now a standard procedure Robertson and Beck measured the dilution of injected gum acacia. To the gratification of the clinician the physiologist demonstrated that the measured reduction of blood volume correlated closely with the severity of the clinical shock

Thus by experiments and clinical investigation three things were shown which the physiologist had suspected from his earlier studies on the circulation and colloid osmotic pressure First blood loss had taken place and was dominant in producing the failing circulation second injection of a noncolloid electrolyte solution had but a transient effect and third a colloid solution was needed to maintain the circulating blood volume and blood pressure All three pointed to the essentiality of an intact intravascular compartment Also at the end of World War I the blood types needed for successful transfusions were worked out and transfusion gradually was established as a common clinical practice

At the beginning of World War II attention was centered on possible blood substitutes It was known that whole blood had but a limited life and was difficult to transport Therefore blood plasma and other plasma substitutes were developed The physiologist knew that such substitutes would have a limited usefulness since they do not provide for the oxygen-carrying capacity of the red blood cells Trial promptly proved their inadequacy As the war progressed more and more evidence indicated a need for whole-blood transfusions Blood banks and donors had to be organized in each field Not until the Korean War of 1950–53 were blood preservation programs and communications developed to the extent that civilians could provide the amounts of blood needed in the battlefields

Once the limitations of plasma replacement were recognized and adequate numbers of transfusions became available two further fields for investigation appeared, namely so-called irreversible shock and toxic shock. When shock from an inadequate blood volume has existed for a number of hours unrelieved by transfusion even massive transfusions may be unavailing in restoring blood pressure and maintaining life This state has been termed irreversible shock and has been encountered both clinically and experimentally Mere restoration of an adequate blood volume by transfusion is not sufficient to restore life Presumably organ damage has occurred during the period of shock. The present thinking envisages that oxygen lack has been responsible Knowledge regarding the irreversible state has also brought the realization that mere restoration of a normal extracellular environment both the intravascular phase and the extravascular interstitial fluid is not sufficient Perhaps the intracellular milieu has been disturbed and until the changes are recognized the direction that therapy should take is unknown

Toxins and Infection

World War I closed with the clinician and the experimental physiologist agreed that there was strong evidence for the exist ence of a toxin as a principal cause of shock Gas gangrene of bacterial origin had been recognized but such gangrene was considered a rare cause of shock Tissue toxins the products of cell breakdown were postulated with histamine the prototype Experiments between the two world wars discounted the significance of tissue toxins and in World War II the importance of bac teria as the source of toxin emerged with full force Despite this recognition of the significance of bacteria the idea of harm ful cell breakdown products lingers on for future research to clarify and identify or dispose of

Three sets of observations led to the con cept of tissue toxins as a contributing or primary cause of shock during World War I First, surgeons at the front noted the de velopment of shock after the release of a tourniquet where no visible hemorrhage followed the release Absorption of a toxin from the tissue below the tourniquet appeared as the only explanation In his discussion of the toxin theory Cannon quoted several cases He was much impressed by the following

> Gregoire has reported the analogous case of a lieutenant caught in a dugout after a shell burst His left thigh was compressed between two logs Thus he remained for twenty four hours alert and guiding the efforts of those who were delivering him. His general condition was good but he was pale with a pulse small and rapid and slightly accelerated respiration There was no wound the foot leg and knee however were purplish and cold above the knee there were two deep hollows formed by the pressure of the logs Some hours after his rescue the officer became restless and al though treatment for shock was undertaken he died thirty two hours after the pressure was removed from the leg There was no indication of nervous depression and no bleeding in this case The shock appeared on permitting the circulation to return to the damaged tissue.

Second experiments traumatizing a limb beyond a tourniquet were undertaken by Cannon and Bayliss A profound drop in blood pressure followed release of the tour niquet It was also found that if a tourni quet was left on for an hour without traumatizing the limb a similar fall might ensue Cannon weighed the limbs after restoration of the blood supply and could find no increase in weight to account for loss of blood and he was therefore forced to the conclusion that a toxin was washed back into the general circulation

Third just prior to 1914 Dale and Laid law had isolated histamine a substance found in many tissues which when injected into the general circulation was followed by a profound prolonged drop in blood pressure comparable to that of other shock ing mechanisms Dale recognized its simi larity to peptone or anaphylactic shock. Because of its generalized distribution in tissues and its extraordinary properties in lowering blood pressure it was natural that it should be seized upon by physiologist and clinician alike as a probable toxin available to be washed out of tissues after the cells had been disrupted by trauma. Cannon also conceived of bacterial action as liberating histamine instead of the bacteria produc ing specific toxins of their own So firmly rooted was the concept of tissue toxins and histamine as the prototype that when Thomas Lewis found evidence of a tissue toxin in his experiments on the "triple response" of skin he termed the hypothetical toxin "H substance " after histamine

Such was the idea of histamine as a tissue toxin in 1928 Pulmonary reflexes were being studied and a drug was desired which would raise the pulmonary artery pressure Histamine has the extraordinary property of raising the pulmonary artery pressure while at the same time lowering the systemic pressure Histamine was expensive and it seemed like a good idea to have the animal produce its own histamine Therefore a tourniquet was placed on the hind leg of an animal and the muscle distal to it traumatized At the point in the experiment at which the rise in the pulmonary artery pressure was desired the tourniquet was released Amazingly the pulmonary artery

pressure fell rather than rose indicating that the fall in systemic arterial pressure which also took place was due to something other than histamine The tourniquet reac tion was then studied and the release of the tourniquet was found to be followed by a fall rather than a rise in pulmonary artery pressure

This led to an investigation of the tourniquet response Although the exact mechanism is not clear it is apparently a vasomotor reaction induced from the periphery and is not due to a toxic substance swept into the circulation This deduction is made from the following experiment

The changes in blood pressure were followed in a cat whose leg, severed except for its nerve supply was perfused with blood from another cat (see Fig 88) The systemic arterial pressure of the first cat (cat A) was measured through a cannula in one of the carotid ar teries A tourniquet was placed at the upper end of one hind leg and left on for an hour In the meantime the other hind leg was ampu tated except for its nerve supply—the sciatic femoral and obturator nerves A second cat (cat B) was heparinized and one of its femoral arteries connected by means of a cannula to the femoral artery of the incompletely ampu tated leg of cat A distal to the line of amputa tion The separated leg of cat A was thus prepared for sudden perfusion at systemic ar terial pressure of cat B by opening the connect ing cannula

When the preparation was complete and the tourniquet had been applied for an hour the tourniquet was released a prompt drop in systemic blood pressure was *observed in cat A* with recovery back to the pre-release level in approximately 5 minutes (Fig. 88 1) After recovery of the blood pressure of cat A was established the circulation to the incompletely amputated leg was suddenly opened from cat B A comparable drop with gradual return of the systemic blood pressure of cat A was recorded

In spite of repeating this experiment many times its full and exact meaning has not been determined *The fall in blood pres sure* invariably followed release of the tourniquet on the unamputated leg provided that the tourniquet had been in place for at least 30 minutes The fall followed perfusion of the incompletely amputed leg in only one half of the experiments

These experiments of 1928 in Church ill s laboratory brought the first doubt about a toxin as a cause of shock Seven years later comparable experiments were re *ported by O Shaunessey and Slome* It remained for Blalock in 1931 to add the most important negative evidence He repeated the experiments of Cannon traumatizing a hind limb of a dog and then comparing the weight of the traumatized limb with that of the contralateral untraumatized limb In order to insure that the amputations of the leg were carried out at comparable levels he carried out a hemisection of the pelvis. This allowed exact anatomical separation Blalock found that the traumatized limb in variably weighed more and by an amount which in terms of blood lost fully ac counted for the observed circulatory insuf ficiency He concluded that the earlier experiments had led to a wrong conclusion because the amputation carried out at a lower level of the leg was irregular and faulty Thus World War II opened with the toxin theory of shock pretty well abandoned

It was not long before the issue of toxins was again being investigated Aub Zamec nik and their collaborators experimenting on a dog found a toxin being generated in the gastrocnemius muscle which had been shut off from its arterial circulation for 4 hours The toxin was isolated and found to be that of a clostridial organism not a cell breakdown product. It was also found that it was virtually impossible to make a wound anywhere in the dog without clostridial con tamination because the dog's skin is constantly smeared with clostridia. Blalock later found a comparable toxin in the thoracic duct lymph of dogs whose legs had been crushed by a clamp It appeared probable that many of the physiological experiments carried out in the past which showed evidence of toxins but without *bacterial control might well have been* due to clostridial infestation at the experi mental wounds Supporting evidence for clostridial toxins as a result of liver injury had already been obtained by Dragstedt and Andrews and again recently by Fine and his colleagues

Firm clinical evidence was also accumu lated during World War II indicating that bacteria flourish in traumatized tissues particularly those denuded of blood supply by the trauma If these tissues are left in the body toxins presumably bacterial tox ins are absorbed This has led to wound debridement First practiced in World War I in the prevention of gas gangrene debri dement became standard procedure in the management of the wounded in World War II and also in civilian practice It was used with great effect in the Korean War Failure to cut away devitalized tissue exposes the patient to severe toxemia and shock of in fectious origin

It has thus come to be realized that toxins may be a contributing factor in traumatic shock and that they come in large measure from bacteria generating in the wound since bacteria multiply rapidly in a wound particularly that with devitalized tissue Theoretical toxins from tissue disintegra tion are certainly much less of a problem and not of practical importance unless they are operating in that little-understood state of irreversible shock.

FAT EMBOLISM

From time to time patients with frac tures of a major bone particularly the fe- mur die in shock and the striking finding of postmortem examination is capillaries of the lung and brain filled with fat The the- ory that this finding represented fat embo- lism was first suggested by Groeningen in 1885 The source of the fat was considered to be the marrow of the fractured bone

The possibility of fat embolism has been investigated experimentally One of the first experimenters was W T Porter Pro- fessor of Physiology at the Harvard Medical School, who worked on this problem during World War I Large doses of fat have been found necessary to cause the death of ani mals and it is difficult to see just from what area a comparable amount of fat could be mobilized in the human being An occa sional case of the phenomenon continues to be observed from time to time but it must be admitted that the significance of fat embolism in shock is still subjudice No practical measures are known which can be taken against its occurrence—if indeed it is a reality

STATUS THYMICOLYMPHATICUS

Occasionally a seemingly well person dies immediately when exposed to trauma Postmortem examination reveals an en- larged thymus and hyperplasia of lymphoid tissue throughout the body The casualties are usually adolescents or young adults The following typical example was re- counted by Ludwig Pick former Professor of Pathology in Berlin He had performed the autopsy when a pathologist in the Ger man Army in World War I A fat dumpy adolescent boy of 17 had just been con scripted into the infantry On one of his first days of training he and his comrades had to ford a river The water was cold On plunging in he died immediately while all his comrades ran through unscathed Lym phatic tissue everywhere including that in the thymus was hyperplastic This rare clinical picture continues to fascinate pa thologists and endocrinologists Lymphatic tissue is more prominent in youth than in adults but that a separate clinical en tity exists is by no means certain Although thymic or lymphoid hypertrophy may be found in patients with adrenocortical in sufficiency the relation to shock is prob- lematic Until understood, the possibility of this condition must be considered in any person dying suddenly when exposed to trauma particularly if the trauma was mild.

ENDOCRINE EXHAUSTION

Much as vasomotor exhaustion has been considered as a cause of shock, so has a pos sible endocrine exhaustion been examined and deliberated During World War I which followed so soon after the discovery of adrenalin possible failure of the adrenal gland was postulated as a cause of shock. Evidence to support this concept has been

considered negligible The matter of the endocrine glands having a causative role in shock simmers down to the following Any patient with a severe endocrine disease hyperactivity or deficiency withstands trauma poorly Thus a patient with severe hyperthyroidism or advanced myxedema does not tolerate an accident in a normal manner Similarly a patient with pituitary insufficiency responds poorly and most of all a patient with severe Addison s disease Unless supported with large additional doses of corticosteroids such patients will *succumb to even minor* trauma

The failure to respond well to trauma has several aspects Certain conditions—namely myxedema, hypopituitarism and Addison s disease—are associated with a restricted blood volume In other conditions—for example hyperthyroidism acromegaly and Cushing's disease with hypertension—the heart is already overburdened Then there are diseases of intermediary metabolism which may prevent or retard mobilization of substances essential to the body s defense. Diabetes mellitus is an example When present, endocrine disease should be treated vigorously with the appropriate quieting or substitution therapy In the treatment the normal metabolic and endocrine response to trauma is to be considered Thus in treating a known diabetic for example the hyperglycemia and glucosuria induced by the trauma is to be taken into account

Trauma to Specific Body Areas

Trauma to specific *body areas results in* special consequences Blows to the jaw the abdomen (the so-called "solar plexus") and to the testicle classically induce sudden collapse This collapse is in part motivated by pain and in part probably by a reflex inducing vasomotor collapse Findings regarding automobile accidents have recently confirmed that a blow to the chest in front of the heart can be a cause of cardiac arrest. Such a blow may be followed by an effusion into the pericardium which must be recognized and relieved promptly Both immediately and when the pericardial effusion develops blood pressure is reduced

Direct trauma to the heart and lungs such as lacerations or stove-in chest, may also produce shock rapidly by embarrassing circulation and respiration These conditions need obvious specific therapy which is described in Chapter 36 dealing with Chest Injuries. Likewise trauma to the kidneys spleen, liver and intestinal tract must be kept in mind because these organs when damaged are sources of hemorrhage and infection needing *prompt attention* These are also considered in Chapter 37 on *Management of Abdominal Injuries*

TREATMENT

The treatment of shock is best considered in phases the initial the postrestitution the intraoperative and the postoperative Each of the factors discussed above under Pathological Physiology should be considered during each phase and the management of each should be fitted in as a part of the total plan of therapy It should be emphasized that therapy must be prompt generous and whenever possible preventive since prevention is always more economical than treatment after shock is established

The phases of traumatic shock vary from patient to patient, depending on the nature and extent of the trauma and the availability of treatment. When an operation is mandatory it may be carried out early if therapy was prompt If shock supervened operation must be postponed The need for therapy *both during and after operation* will depend on the special circumstances Because of the diversity of patterns of the phases the presentation of treatment will follow the factors as described above under Pathologic Physiology

Treatment of Neurogenic Shock

The collapse of primary shock resulting from anxiety pain or a specific blow is

treated by laying the patient prone Usually without resort to extreme measures the prone position returns the blood from the veins to the right side of the heart and the heart resumes pumping Blood pressure is restored and consciousness returns Where consciousness was not lost steadiness returns At this point in the management of the patient it is wise to know whether there has been antecedent signs or symptoms of heart disease Only if such disease has been present is any specific therapy needed for the heart

Treatment of Blood Loss

Conditions leading to blood loss need prompt attention Whether the bleeding is from a wound open to the outside or into a body cavity or from a fascial space or torn muscle pressure on the vessel or prompt ligature where pressure is not possible is the first essential If there are a number of casualties and little help the application of tourniquets to torn limbs may be necessary but if pressure directed at a major vessel stems the flow and help is plentiful, the use of tourniquets should be avoided. It is to be stressed again and again that prevention of blood loss is far more economical and time saving than transfusion after hemorrhage has taken place

The greater the hemorrhage and the longer the period between hemorrhage and the start of therapy the more prompt a transfusion should be The amount of whole blood to be given is that amount which is estimated to have been lost Frequently it is difficult to estimate the volume that has been lost still an estimate has to be made Ideally the blood volume should be determined but such a determination to be accurate is time consuming and there is no time to measure and calculate The hemoglobin and hematocrit readings are poor safeguards for both are normal immediately following a hemorrhage even a massive one Hours must pass before the blood is diluted sufficiently to indicate the severity of the hemorrhage

The systolic blood pressure also may not indicate the full blood loss A small pulse pressure with high diastolic pressure and a rapid pulse both indicate an impending loss of vasomotor compensation and a drop in total blood pressure Pallor sweating and nausea are important signs of strained compensation All of these clinical signs are better guides than the laboratory findings

Once blood pressure has been restored to normal and the signs of vasomotor compensation have vanished the adequacy of fluid therapy is then to be guided by renal output If the blood volume is still constricted kidney blood flow and renal output are reduced In case of doubt the patient should be catheterized with an indwelling catheter and the volume and specific gravity of the urine measured hourly

Plasma or other colloidal plasma substitutes are only to be used as stopgaps when blood is not available They have no oxygen carrying capacity and do not replace red blood cells They are better than noncolloidal solutions because they maintain the circulating blood volume Noncolloidal salt and glucose solutions are better than nothing at all.

Treatment of Infection

Wound care is an essential part of the treatment of traumatic shock and is to be fitted in as circumstances permit and as the patient s condition warrants All wounds are to be protected against bacterial contamination until the proper facilities are available for debridement. As soon as the patient s circulation is in good balance and transfusions are available wound debridement is to be carried out. By prompt wound protection and wound care infection as a contributing cause of shock is minimized

Special Considerations in Treatment

Sucking chest wounds and cardiac tamponade may by their very urgency take precedence over every other measure The care of these injuries is obviously not to be delayed for lack of blood to transfuse for

delay may be fatal Their surgical management early and late is described in Chapter 36

The illusory and uncertain conditions of fat embolism and status thymicolymphaticus permit of no therapy Supporting endocrine therapy has been alluded to in this chapter but is considered in greater detail in Chapter 3 on the Metabolic Response to Trauma.

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12 

Anesthesia for the Injured

THE FIRST question to be decided here is when anesthesia and surgery should be undertaken in the wounded person. Unquestionably the passage of time is against the patient's welfare Delay is especially serious of course when hemorrhage continues No complete attempt will be made in this section to describe the essentials of the preparation of the injured patient for anesthesia, since that has been done in Chapter 9 But it should be emphasized in passing that anesthesia in a person whose hemoglobin is below the level of 11 Gm. per 100 cc. is fraught with great and usually needless hazard It must further be recognized that hemoglobin determinations will not adequately reflect blood loss until a good many hours after bleeding has stopped Appraisal of blood lost to the outside can be made from inspection of the size of the wound blood-soaked clothing or blood spilled Internal blood or plasma loss can be estimated from the swelling of an extremity

While it is difficult and in the view of some unwise to try to establish a rule-of thumb for fluid and blood administration it should be borne in mind that a useful understanding of the quantities of blood and blood substitutes can be obtained by consideration of the following It must be recognized that in any disaster where several persons are injured blood will almost always be in short supply In such cases there is an indication for the use of blood fractions or blood substitutes the so-called "plasma expanders" It must be recognized too that there are limits beyond which one should not go in resuscitating the person who has been subjected to physical violence For example if a person has been bleeding or is bleeding and if blood fractions or blood substitutes are administered to the point of restoring blood pressure or blood volume to normal before definitive surgical care is undertaken then the limited supply of hemoglobin retained by the subject will be washed out and the stage set for a critical situation. Experience has shown that, when patients are obliged to wait for definitive surgical care it is safest to restore systolic blood pressure to about 80 mm Hg. At this level very little bleeding will occur but also at this level no serious damage to vital organs will take place in a person whose blood pressure had previously been normal. Experience has shown too that in previously well persons if the systolic pressure has been restored to a level of 80 mm. Hg and is rising it is then safe to undertake anesthesia It must be recognized that in certain critical situations—as for

example internal hemorrhage from a sev ered great vessel or great fecal contamina tion of the peritoneal space and so on—it may never be possible to restore the blood pressure even to 80 mm Hg. Data are available to show that the greatest blood loss and the most severe wound shock of the common wounds occur with open frac ture of long bones

This experience with anesthesia after hemorrhage was gained with the simple technique of using nitrous oxide to intro- duce ether-oxygen inhalation Not enough experience has yet been acquired with the currently much used muscle relaxants to know whether these agents will be good or bad in the treatment of wounded persons As described below (p 127) the use of thiopental sodium (Pentothal®) has been shown to be exceedingly dangerous in seri ously wounded patients and there is doubt that it will be any safer if used with the muscle relaxants

It has been abundantly demonstrated that an incorrect choice of anesthesia can nullify careful preparation of wounded pa tients for surgical intervention Examples of this will be cited in the following pages

In any consideration of the handling of wounded patients it must be borne in mind that this country may be confronted by a large civil or military disaster in the not remote future Such a situation will entail the necessary use of many partly or poorly trained anesthetists The following remarks have been planned with that possibility in mind

PREANESTHETIC MEDICATION

Two agents atropine and pentobarbital sodium are of real importance in preanes- thetic medication If a person is in pain then a narcotic such as morphine should be added to the preanesthetic medication Far too often the fact is overlooked that per sons with grievous wounds have little or no pain. The routine use of a narcotic often in large dose in such circumstances is to be condemned for the patient not in pain The use of atropine 0 6 mg and pentobarbital sodium 90 mg administered intramuscu larly constitutes desirable preanesthetic medication

INHALATION ANESTHESIA

Inhalation anesthesia is preferable for a patient who has multiple wounds or when the major body activities are to be invaded by the surgeon. Preparation for inhalation anesthesia requires that the stomach be emptied This can best be accomplished by the insertion of the endotracheal tube which is moved in the nasal pharynx in such a way that vomiting is induced The stomach cannot be dependably emptied by any means short of vomiting *It must be borne in mind that food eaten 18–20 hours before anesthesia is undertaken may be re gurgitated if the patient is subjected to pain before the stomach has emptied* It is also to be emphasized that the aspiration of vomitus is probably the commonest serious and often fatal needless accident that oc curs in hospitals Death from this cause is rarely excusable

Useful inhalation anesthesia for minor procedures such as simple superficial de bridement of wounds painful changes of dressings etc can be accomplished with nitrous oxide This agent is also a satisfac tory means of inducing ether anesthesia It should never be employed with less than 20 per cent oxygen Too few persons are aware of the fact that ether anesthesia can be induced particularly easily in the seri ously wounded with no preliminary agents

Until we have more information than we have at present it must be concluded that ether is the choice for use in the seriously wounded particularly for major thoracic surgery and in caring for open fractures of the long bones Experience has shown that ether is the choice when patients are in shock or when shock is feared (but opera tion must be performed without delay) or whenever the circulatory system may have been impaired by the wound and general anesthesia is necessary Those with experi- ence in dealing with the seriously wounded have widely recognized ether as the desira

ble agent for use in these persons It is also evident that it is valuable in the less seriously wounded

Ether is highly inflammable and explosive In hot climates the ether can should be kept on ice or in wet bags exposed to a breeze if no ice is available

Ether anesthesia is best administered through an endotracheal tube A No 32 French tube is satisfactory in most adults Sizes larger than No 34 French are not necessary The introduction of these tubes can be greatly facilitated by using a soft copper wire stylet

CYCLOPROPANE ANESTHESIA

Cyclopropane anesthesia has not been used widely enough in severely wounded patients to assay its degree of usefulness for this purpose Since this anesthesia requires a closed system and the transport of considerable equipment it is unlikely to have great usefulness in military practice There is also the belief by some experienced surgeons that bleeding is promoted by cyclopropane anesthesia In addition to a possible bleeding tendency cyclopropane produces poor muscle relaxation in most cases Cyclopropane is highly explosive

Currently the fashion is to anesthetize many patients with one of the muscle relaxants in conjunction with thiopental sodium As referred to above there are objections to the use of thiopental sodium in bled-out or otherwise wounded patients In the North African–Mediterranean Theater where 30 months of active warfare took place it was the consensus of *all* experienced surgeons that severely wounded men tolerated thiopental sodium very poorly indeed Some badly wounded men died from very small doses of this agent. And as stated above there is no reason to believe that the combination of thiopental sodium in conjunction with a muscle relaxant will be any safer than a barbiturate alone although there is some evidence to the contrary

As mentioned above any plans or preparations for handling wounded persons have as a background the possibility of a major civil or military disaster The complexity of the muscle-relaxant techniques is undoubtedly such that many needlessly fatal accidents will be produced when partly or poorly trained anesthetists try to use these techniques in critically injured persons Indeed the question as to whether these agents are satisfactory in the wounded has not yet been established even where highly skilled anesthetists are involved

INTRAVENOUS ANESTHESIA (THIOPENTAL SODIUM)

The simplicity with which thiopental sodium anesthesia can be administered (especially the compactness and simplicity of the necessary equipment) the ease with which a smooth induction can be produced even by the inexperienced the prompt awakening of the patient and the number of cases an inexperienced man can "get away with" even though his actual death rate may be unreasonably high in comparison with what it should be—all these factors have tended to outweigh the fact that thiopental sodium is a powerful tool that overdosage is not always easy or possible to overcome that the use of this drug is incompatible with certain types of injury and that its fatal dose does vary widely from one patient to another

Unquestionably thiopental sodium is of great value but it is equally certain that its use is contraindicated in the seriously wounded Its use is unwise in the presence of certain injuries For example (1) it should not be used when the patient is suffering from morphine overdosage (2) It should not be used when shock is present or when shock is anticipated (It should be borne in mind that the following wounds or conditions are very often associated with shock penetrating wounds of the chest or abdomen open fractures of the long bones and severe hemorrhage even when it comes from otherwise trivial wounds Thiopental sodium should never be used in these conditions) (3) The use of thiopental sodium is probably unwise when incision of a cervical abscess is to be undertaken Deaths

have occurred under such circumstances Apparently inflammation in the region of the carotid bodies or sinuses causes sensitization of the reflexes which arise there This sensitization may account for the notorious incidence of sudden death during such operations Since thiopental sodium and other barbiturates are not especially effective in depressing these reflexes (indeed there is some evidence that such reflexes are actually heightened by barbiturates) they should not be used in most cases of this kind

In some cases where compound fractures of the facial bones may also be present thiopental sodium may be the reasonable choice for handling a cervical abscess In such cases the following precautions should be observed Heavy atropinization should be used in the preanesthetic medication Surgical intervention should not be begun in patients with an irritable carotid sinus until at least 10 minutes after the induction of thiopental sodium anesthesia Pressure on the carotid arteries should be avoided and if feasible the plexuses of nerves should be blocked with local anesthesia at their bifurcation

In another group of patients the use of thiopental sodium may be at times debatable but its use unwise nevertheless (1) In general the administration of thiopental sodium should be avoided when the operative position or procedure may interfere with the airway or may make artificial respiration difficult as for example in operations that must be carried out with the patient in the face-down position and in operations on maxillofacial injuries or other injuries involving the airway Local anesthesia is usually not adequate for handling these cases so ether with endotracheal intubation is often the choice (2) Skillful or lucky surgeons may often use thiopental sodium as the chief anesthetic agent for intracranial surgery with success but its employment as the principle anesthetic agent in this type of surgery is usually not wise for the following reasons Such operations are long and thiopental sodium anesthesia is best limited to half hour procedures Intracranial operations are usually associated with great blood loss and extensive blood loss contraindicates the use of thiopental sodium When the blood loss is not great thiopental sodium may be used as an adjunct to local anesthesia as a sleep-producing agent rather than as an anesthetic The drug sometimes unexpectedly causes respiratory depression this produces immediate swelling of the brain and it may make an intracranial procedure difficult or impossible. (3) Experience has shown that patients with severe burns tolerate thiopental sodium anesthesia very poorly possibly because of a great reduction in circulating blood volume caused by plasma loss from or into the burned area.

The great field of usefulness of thiopental sodium as far as the treatment of trauma is concerned is in providing anesthesia for short procedures when relaxation is not needed in patients in good condition with slight wounds and with little blood loss The supplementation of thiopental sodium with 50 per cent nitrous oxide and 50 per cent oxygen is often desirable

LOCAL AND REGIONAL BLOCK ANESTHESIA

Regional block anesthesia is of course desirable for use in patients who may have full stomachs when the injury lends itself to a single block or infiltration. Brachial plexus blocks are exceedingly useful in the treatment of injuries of the upper extremities However when a person has multiple wounds or when major body cavities must be invaded local anesthesia is rarely satisfactory On the other hand it must be recognized that certain blocks do a great deal to facilitate the comfort of the patient either before or after major surgery For example intercostal nerve block or paravertebral block will often greatly improve respiration Block of the nerves controlling major blood vessels in extremities may help to relieve vascular spasm which has been causing ischemia

Epinephrine in 1 200 000 dilution will greatly prolong—even triple or quadruple

—the action of local anesthetic agents Or 0 5 cc of a 1 1 000 solution of epinephrine can be added to 100 cc of 1 per cent procaine hydrochloride Higher concentrations of epinephrine than this may be dangerous and are often unnecessary Epinephrine or other vasoconstrictor agents are not to be used with local anesthetic agents in surgery of the fingers toes ears nose penis or scrotum if used sloughs may be caused Epinephrine is not to be added to local an esthetic solutions if their action is to be augmented with cyclopropane chloroform ethyl chloride or tribromoethanol (Avertin®) for ventricular fibrillation of the heart may result.

Persons sensitive to a local anesthetic agent, or patients who have received an overdose will often have convulsions Specific treatment for reactions is afforded by the soluble barbiturates—for example 0 1 Gm of pentobarbital sodium administered intravenously The dose may be repeated Reasonable doses of procaine hydrochloride will not exceed either 150 cc. of 0 5 per cent 100 cc of 1 per cent or 40 cc of 2 per cent solution These maximum total doses should not be administered in less than a period of 1 hour to healthy adults in good condition Local anesthetic agents should be used with great caution if at all and in small doses in patients with liver disease Inquiry must always be made regarding the patient s sensitivity to local anesthetic (and all other anesthetic) agents

SPINAL ANESTHESIA

Spinal anesthesia is never acceptable for persons recently and seriously wounded They tolerate it poorly and it may precipi tate profound shock

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13 

Facial Injuries

INJURIES TO the face frequently accompany other injuries to the body A severe blow to the face may produce extensive lacerations of the soft tissues without fracture or may cause multiple fractures with only soft tissue contusion Usually there are injuries both to the soft tissues and to the bone structures Fracture must not be overlooked because of the severity of the lacerations or edema of the facial tissues The fracture and the lacerations should both be treated promptly and definitively if the patient s general condition warrants

In few injuries is the final outcome so directly dependent on early proper care as in the treatment of a severe facial injury The bony and cartilaginous framework of the face supports the soft tissues and teeth and provides attachment for the muscles of expression, and the function of chewing and eating depends on a normal anatomical and functional relationship between these structures Failure to restore the displaced bone to its normal position or failure to resolve the puzzle of a jagged laceration of the eyelid nose or mouth may result in disfigurements which will permanently alter the appearance and function of the face Only by early reduction of all fractures and adequate splinting of the fragments before fixation of the bones has occurred can the normal contours of the face be restored and only by accurate layer closure of the soft tissues will function be re-established and scarring minimized

The surgeon will be awed by the maze of techniques appliances prejudices and conflicting opinions found in the surgical literature in recent decades It is not our purpose here to review all the methods that have been used in treating facial injuries but merely to report those that have proved most simple and effective

EMERGENCY CARE AND TRANSPORTATION

In the emergency care and transportation of patients with severe facial injuries, three problems of concern to the surgeon, any of which may be lifesaving, are important the arrest of hemorrhage the establishment and maintenance of an adequate airway and the support and protection of the damaged tissues

Local pressure or packing of the wound or wounds with sterile gauze is usually sufficient to control hemorrhage but clamping of a lacerated large blood vessel is sometimes necessary The clamp may be left in place or the bleeding vessel ligated if feasible In all of these manipulations interference with respiration or the respiratory passages is to be avoided Prompt blood replacement should be instituted in conjunction with the control of hemorrhage

The normal airway may be obstructed either by backward displacement of the tongue and floor of the mouth or by hemorrhage A collapse of the mandibular arch or a backward and downward displacement of the roof of the mouth will crowd the tongue against the pharynx Traction on the tongue with a suture or even with a safety pin inserted through the tip or traction on the displaced bone should relieve the obstruction effectively The insertion of an endopharyngeal tube or an endotracheal tube may be desirable In the insertion of either additional damage to the soft tissues must be avoided Tracheotomy is seldom necessary and may add to the patient s difficulties

Support and protection of the damaged tissues by application of a well padded bandage beneath the chin and around the head and face will reduce the possibility of further contamination slow the development of local edema and reduce the patient s local discomfort. Under no circumstances should any but the most urgent manipulation be done until after a careful general evaluation of the patient has been made and he is in an operating room prepared for definitive treatment.

For transporting the conscious patient the upright position has proved best, because the patient is then able to cough effectively and can rid the mouth of obstructing blood or secretion by leaning forward The unconscious patient should be transported in a face-down position because displaced tissue of the mouth will then fall forward away from the pharynx, and the aspiration of blood or vomitus will be reduced to a minimum

EXAMINATION

External lacerations or abrasions of the face will be obvious but the detailed pattern of laceration important in carrying out the repair may be obscured by dried blood or a dressing Gross displacement in fractures will also be obvious Other fractures may be difficult to identify so any patient who has received a blow to the face should be considered as having a fracture until this is ruled out. This calls for a systematic examination of every such patient On inspection any loss of symmetry of the structures of the face should be apparent unless masked by swelling of the soft tissues Also malocclusion of the teeth partial or complete paralysis of the seventh nerve and abnormal or restricted motions of the upper or lower jaws should be noted Drainage of blood or cerebrospinal fluid from the ear or nose may indicate fractures with laceration of the lining skin or mucosa or the dura Membranes of the tongue palate or alveolar processes may be cut by the sharp edges of fractured bones or torn if the bone to which the membrane is attached is displaced

Fractures of the nasal bones and cartilage can usually best be identified by questioning the patient and by direct palpation of any displacement In children even minor displacements may occur and they should be sought for even without the corroborating evidence of bleeding from the nose Within the nasal cavity swelling of the septum may indicate a septal fracture and the formation of a hematoma Laceration of the mucosa following a blow is the most positive evidence of a fracture

The next most common fracture of the facial bones is fracture of the zygoma, which usually results from a direct blow The three major suture lines attaching the zygoma to the maxilla, frontal, and temporal bones are the usual sites of fracture Displacement is usually downward and backward Fracture of the substance of the massive zygoma seldom occurs except by a penetrating object such as a missile By palpating the infraorbital rims at the juncture of the zygoma and the maxilla of the external orbital rim at the junction of the zygoma and the frontal bone or of the zygomatic arch the irregular fracture line or asymmetry may be discovered Anesthesia in the distribution of the infraorbital nerve is common since these fractures may cross the infraorbital canal and either crush or sever the nerve Shattering of the walls of the antrum accompanies fractures of the

zygoma but is seldom identified on examination except by x ray Unless the injury is severe fractures of the zygoma are not associated with malocclusion, but the backward displacement of the bone or the inward displacement of the zygomatic arch may interfere with the forward excursion of the coronoid process and limit opening of the mouth

Fractures of the orbit can be identified by palpation of the orbital rims There may be lateral displacement of the medial wall of the orbit to which the inner canthus is attached Diplopia, partial or complete loss of vision impaired extraocular movements corneal abrasions and damage to the globe must all be checked and recorded before any definitive treatment is considered

The most serious injuries to the facial bones are those crossing the face transversely at the level of the orbits or at the level of the floor of the antrum These are characterized by complete separation of the facial bone structures from the skull, with downward and backward and occasionally rotated displacement. By grasping the upper jaw and immobilizing the head, abnormal mobility can usually be demonstrated. Malocclusion is always present in these fractures usually with premature contact of the molars and an open bite

X ray studies of the facial and jaw bones are important for confirmation of the clinical findings and as part of the patient's record Proper posing of the head is essential for informative films By posing in both the vertical submental (Fig 89) and the Waters (Fig 90) position, fracture and displacement of the rims of the orbits the zygomatic arches the lateral and medial walls of the antrums the bone structure of the nose the alveolar arches and the palate will be visualized Detailed visualization of the nose requires a soft lateral view and an anteroposterior downward view with a small film held against the roof of the

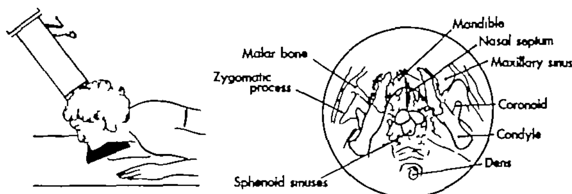


Fig 89 —The vertical submental position showing the pose and the bony landmarks which are useful in interpreting the x ray film

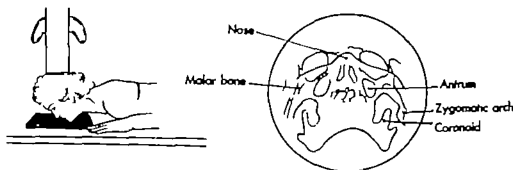


Fig 90 —The Waters position showing the pose and the bony landmarks which are useful in interpreting the x ray film.

mouth Mandibular x ray studies should include views of each side of the jaw the symphysis and both condyles (Fig 91) The direction of the mandibular fracture lines the amount of displacement, the degree of over riding of the posterior fragment and the condition of the teeth adjacent to the fracture line may all influence the method of treatment chosen

GENERAL CONSIDERATIONS IN TREATMENT

Critical injuries of the brain chest and abdomen and major fractures must often take priority over facial injuries in treatment. Examination of the cervical spine should not be overlooked since the force of the blow to the face may be transmitted to that area The definitive care of the facial injury should be postponed until the patient has recovered consciousness or until other critical injuries have been attended to The lacerated edges of the skin can be drawn together with adhesive strips or loose suturing and the displaced bone structures of the face or jaw supported by a bandage Minimal manipulation is permissible in the presence of other injuries to lessen the patient s discomfort and to simplify later repair

If circumstances permit lacerations of the face and fractures of the jaws should receive definitive treatment in the first 12–24 hours after injury before swelling has become prominent and before organization of blood clots or infection develops Delays in the replacement of bone fragments over 7–10 days may make realignment impossible because of the rapid fusion and fixation of the numerous comminuted fragments Lacerations in a child are often best treated by adhesive strips alone A dread of hospitals anesthesia sutures and so forth need never be kindled in the child s mind

Local anesthesia is preferable in the definitive repair of most facial injuries The topical application of cocaine or its equivalent usually suffices for uncomplicated nasal fractures Local infiltration with Novocain® is useful for most skin lacerations but nerve block (infraorbital mental or other) may be preferable to avoid distortion of the soft tissues Nerve block may also be desirable if maintenance of an adequate airway is difficult and if at the same time complete anesthesia of the face is needed

This is accomplished by block of the second and third divisions of the fifth cranial nerve and infiltration of the cervical nerves that extend upward across the body of the mandible In children, general anesthesia may be essential In complex injuries of the face and jaws endotracheal anesthesia is preferable because of the length of the procedure and the desirability of a tube in the trachea during and after the operation However the postoperative dangers of aspiration of secretions and the hazards of immediate fixation of the teeth in occlusion must be kept in mind when general anesthesia is used Postoperatively the endotracheal tube may be kept in place until the patient is virtually fully conscious

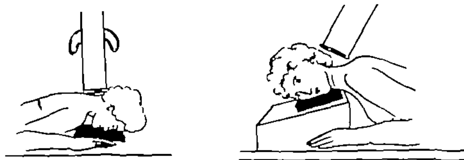


Fig 91 —Positions for x rays of the mandible left posteroanterior right lateral

PREPARATION OF THE WOUND

Thorough cleansing of all facial wounds s an essential preliminary to definitive reatment A local anesthetic may be in ected before the wound preparation or bet tion Loose dirt, hair glass and other for eign bodies and detached chips of bone should be sought for and removed A detailed history of the nature of the trauma producing the injury will furnish helpful clues of what may be found in the tissues.

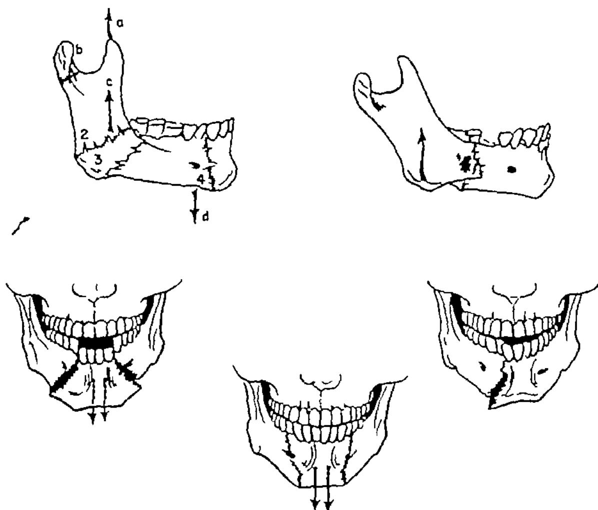


Fig 92.—Sites of fractures of the mandible showing types of displacement resulting from the action of the muscles attached to the fragments *a* direction of pull of temporal muscle *b* attachment of external pterygoid muscle c direction of pull of internal pterygoid and masseter muscles *d* direction of pull of geniohyoid and genioglossus muscles *1* common site of fracture of neck of condyle 2 site and direction of fracture of angle of mandible without tooth in posterior fragment in which over riding of the posterior fragment can be expected as shown in sketch on right 3 site and direction of fracture of mandible with tooth in posterior fragment and in which over riding does not occur 4 common site of fracture in the region of the mental foramen with types of fracture and displacements illustrated below

ter after the preliminary washing Final preparation should include irrigation and gentle scrubbing with mild detergent soap being used If dirt or oil has been ground into the skin vigorous scrubbing with a brush is necessary Despite the trauma of such a procedure it is time well spent and may eliminate the n-ed for a later opera

Debridement of the tissues of the face should be *minimal* in contrast to the complete wound excision recommended elsewhere in the body An ill advised debridement of skin about the eyelids or mouth or the failure to replace skin lost from them may result in a significant deformity "It is better to save tissue which

may die than to sacrifice any which may survive" A piece of skin partly or even completely detached often survives as a free transplant if replaced in its normal position sutured loosely with minimal tension and protected by a firm dressing

MANAGEMENT OF FRACTURES

Fractures of the facial bones differ from most fractures because the displacement is produced by the trauma itself and not by the pull of attached muscles Consequently in the reduction of fractures of the face the displaced bones must be replaced in their original position and held in place against the minimal elasticity of the soft tissues and the force of gravity

The fragments in mandibular fractures on the other hand are displaced by the action of the very powerful muscles of mastication. In the reduction and fixation of these fractures appropriate splinting must be employed to control the pull of the muscles (Fig 92)

Two useful aids in the diagnosis of fracture—malocclusion of the teeth and palpable deformity of the bony prominences of the face—are equally valuable in determining the accuracy of the reduction of fractures of the jaw or face Such simple indicators should be an inducement to utilize direct surgical methods in the treatment of these fractures The final reduction can thus be achieved promptly the patient will be relieved of the discomfort of unstable fragments and the constant adjustment of complicated appliances will be unnecessary These principles are in keeping with the current trend toward prompt reduction and positive fixation of fractures elsewhere in the body The morbidity and duration of hospitalization will be reduced by employing direct and accurate techniques

FRACTURES OF THE NASAL BONES

The nasal bones form the forward and lateral sides of the upper third of the nose They are thin and convex in their lower half but solid in their upper third They are held as if in a vise by the ascending processes of the superior maxilla and they rest on a shelf the nasal spine of the frontal bone

It is imperative that the septal fractures and dislocations be realigned and held in place soon after an injury Rapid organization of the injured parts in malposition

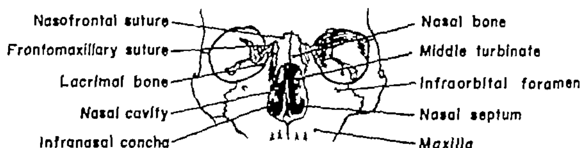


Fig 93 —Fracture of nose obvious from both clinical and x ray (left) examination Fracture was reduced (right) under local anesthesia by inserting a blunt instrument into the nose and elevating the fragment into position elaborate splinting was not necessary X ray studies will not always be so helpful The surgeon must often rely on clinical examination to make a diagnosis of fracture of the nasal bones or nasal cartilages

occurs and makes reduction and realignment impossible after a few days An intact septum that is realigned or a fractured or dislocated septum reduced and held in place will hold the nasal bones and the cartilaginous dorsum in their normal contour Without septal support the nasal bones and cartilaginous dorsum will collapse Fixation of the septum may be accomplished by gentle intranasal packing either petrolatum-impregnated or dry fine-mesh gauze strips may be used Most nasal fractures are of the lower half where the

bone is thin (Fig. 93) They frequently include the thin portion of the ascending process of the superior maxilla. Fractures of the upper half where the bone is thick and quite solid, are less frequent. Rarely are the nasal bones disarticulated in their upper third, for they are held firmly in a

Cerebrospinal rhinorrhea is *not a cor* indication to reduction. Instead, reduc should be carried out as soon as the co tion of the patient permits Reduction immobilization of the bone hasten the ing of the leaks and reduce the likelil of invasive infection of the meninges



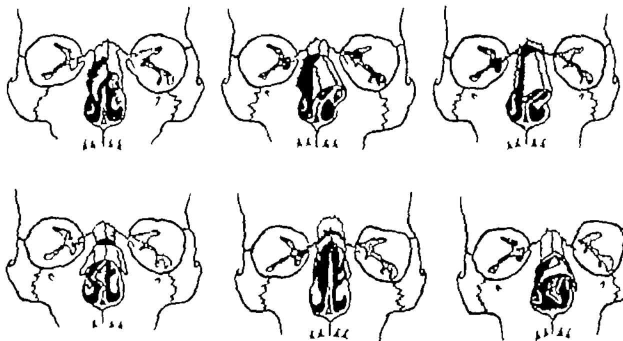


Fig 94 —Types of nasal fractures frequently encountered

facet created by the frontal bone and the ascending processes of the superior maxilla. A fracture there usually results from a crushing blow which separates the ascending processes driving the bone either into the nasal passage or laterally beneath the soft tissue of the cheek (Fig. 94) A depressed fracture in this area often involves the perpendicular plate of the ethmoid in the region of the cribriform plate and is associated with cerebrospinal rhinorrhea

The majority of nasal fractures exc in children may be treated under local a esthesia, using topical anesthesia with the nose and infiltration of procaine or equivalent subcutaneously over the bon Most nasal fractures can be reduced by e vation using a blunt instrument within t nose The fragments can be manipulat and the reduction controlled and check for accuracy by external digital pressu (Fig 95) In badly comminuted fractu

it may be necessary to use a special forceps to grasp fragments of bone and bring them into accurate position Most nasal fractures may need nothing more than an adhesive support or a metal or dental-composition

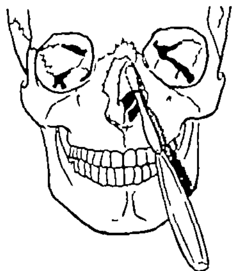


Fig 95 —One method of reducing a nasal fracture—using a blunt instrument within the nose. Palpating fingers check the reduction externally

splint. Those which have lost the support of the septum require additional splinting which may be provided either by a lifting splint introduced within the nose and supported by a head cap or by the more simple and effective method of through and through wires passed between the comminuted fragments and fastened to pieces of soft metal molded to the side of the nose

A common mistake that is made in attempting to reduce a nasal fracture is to pass the elevator too high within the nose so that it rests either beneath the unbroken nasal bones or beneath the nasal process of the frontal bone Care should be taken therefore to make sure that the elevator lies beneath the displaced fragments only

Fractures of the Zygoma

The zygoma is roughly a flat bone with three main articulations — articulations with the frontal bone the superior maxilla and the zygomatic arch of the temporal bone The largest and firmest articulation is that with the superior maxilla Fracture at this articulation usually involves the maxillary antrum The bone itself is rarely fractured but is displaced in the direction of force of the blow The displacement may be posterior medial or both and with an upward or downward rotation The posterior surface of the zygoma which is the anterior wall of the temporal fossa is in close contact with the coronoid process of the mandible Backward or medial displacement may limit motion of the coronoid process (Fig 96) The outer inferior third of the floor of the orbit is formed by the zygoma so that displacement downward inward or upward will cause a change in the volume of the orbit. This in turn may produce diplopia by pushing the globe forward when the orbital contents are compressed or by inward and downward displacement of the globe if the orbit is enlarged The lateral



Fig 96 —Depressed fracture of zygomatic arch which impinged on the coronoid process of the mandible The chief complaint was limitation of motion of the mandible The temporal approach was used for reduction A blunt instrument passed beneath the temporal fascia and the zygomatic arch was used to pry the fracture outward No splinting necessary

palpebral ligament is attached to the frontal process of the zygoma so that the eye is rotated when the zygomaticofrontal suture is separated and the zygoma displac

downward This anatomical fact is impor tant in planning the reduction

The direction of displacement of the zygomatic bone which can usually be ac curately determined from examination and by x rays will influence the selection of the method of treatment. There are several methods of reduction of fractures involving the zygomatic bone each of which has spe cial indications

When the zygomatic arch alone has been fractured inward or when the zygoma has been rotated posteriorly toward the tem poral fossa reduction by the temporal approach of Gillies is indicated (Fig. 97) An incision is made parallel to the temporal artery within the hairline about 3–4 cm anterior to the ear The temporal fascia is

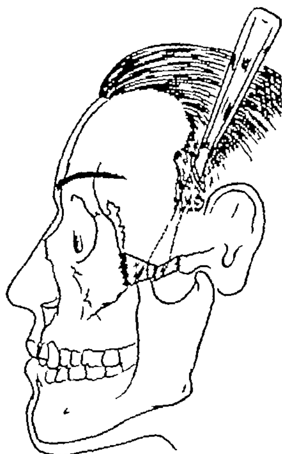


Fig 97 —The Gillies method for elevation of depressed fractures of the zygomatic arch An incision made within the hairline permits access to the temporal fossa by an instrument passed beneath the temporal fascia

exposed and incised and a blunt tipped ele vator is inserted beneath this fascia and passed downward beneath the temporal arch Using the instrument as a lever th bones can be sprung back into position I considerable force is necessary a folde gauze pad may be placed beneath the har dle of the instrument as a fulcrum

The temporal fossa can also be ap



Fig 98 —Intraoral approach to fractured zygoma. The displaced bone is reduced by a blunt instrument passed through the comminuted anterior wall of the maxillary sinus. The reduction may be checked with the pal pating finger and compared with the opposite side

proached intraorally and reduction carried out from below Through an incision made in the buccal mucosa just above the last molar tooth a blunt elevator is passed upward parallel to the anterior border of the ramus and into the temporal fossa Here the elevator lies behind the displaced zygoma which can then be moved laterally or anteriorly

The most ubiquitous approach for zygomatic fractures is through the antrum because the blow in most fractures is from the front and the bone is driven backward and downward with the antrum The antrum can be entered either through an incision in the buccal fornix above the bicuspid teeth or through an intranasal window beneath the inferior turbinate In the former a blunt instrument passed between the frac

ture lines of the anterior wall of the antrum is used to engage and elevate the bone (Fig 98) The accuracy of reduction may be checked by comparison with the uninjured side Usually the reduced fragments lock goma from the frontal bone It may be necessary to expose the area of the fracture directly by incision through the overlying skin Then through two drill holes one in the frontal bone and the other in the zy



Fig 99 —Top compound injury of the lateral orbital wall caused by a hook that avulsed the bone and overlying soft tissue Bottom left x ray film revealed fracture of zygomatic arch and lateral displacement of zygoma. The zygoma was exposed through the open wound and wired to the frontal and maxillary bones Bottom right after wiring The soft-tissue wound and the bone healed without complications

themselves in place but if there is much comminution splinting may be necessary A pack in the antrum provides good support for the loose bones but may be uncomforta ble for the patient. The pack is left in place until there is solid bone union usually 2–3 weeks Skeletal fixation is seldom necessary unless there is wide separation of the zy goma, a stainless steel wire can be used to hold the bones together (Fig 99)

Fractures of the Maxilla

The maxilla is attached to the skull by several buttresses chief among them being the ascending process of the maxilla, the

lateral and posterior walls of the maxillary antrum, and the palatal bone The nasal, malar lacrimal, ethmoid and other facial bones any or all of which may be involved in severe fractures of the maxilla, are considered part of the maxillary complex All degrees of fractures of the maxilla are encountered from a crack through one or two of these buttresses to a complete separation of the attachments to the skull These transverse fractures of the upper jaw cross the face either at the level of the floor of the antrum with separation of the alveolar *process from its attachment to the facial* bone structure or at the level of the orbit with separation of the maxillary complex from the skull (Fig 100) The most significant deformity in each of these transverse fractures is elongation of the face caused by the separation of the fractured bones from the skull The teeth are maloccluded as a result of the downward and often backward displacement of the face (Fig 101)

Methods of treating these complex transverse fractures of the face have fortunately kept pace with the universal trend toward prompt and direct reduction and fixation of all fractures Appliances which require special preparation and repeated and painful adjustment and which consequently fail to achieve the immediate and definitive result can be avoided Internal fixation of the displaced fragments to the stable orbital rims

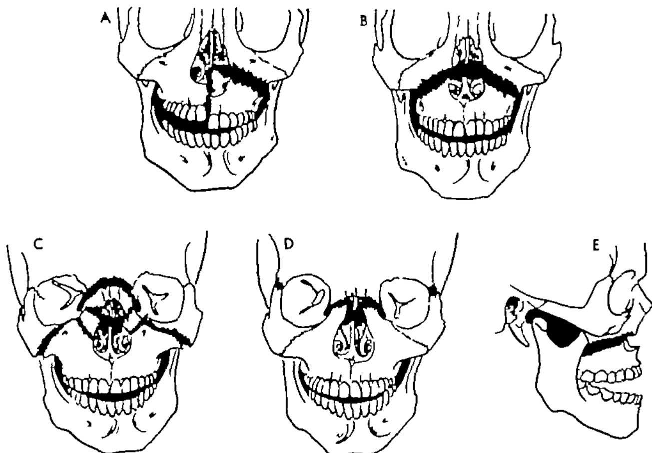


Fig 100 —Several varieties of upper and lower transverse fractures of the facial bones A, alveolar fracture with extension into the antrum and palatal process B lower transverse fracture across the floor of the antrum with complete malocclusion of the upper arch C upper transverse fracture through the complex suture lines of the nasal malar lacrimal and ethmoid bones and involving the zygomaticomaxillary suture lines D upper transverse fracture through the orbits with multiple bony separations in the lacrimal-ethmoid region and zygomaticofrontal suture lines E lower transverse fracture showing backward displacement of the *upper arch and the typical open-bite malocclusion associated with it.*

or to the zygomatic arches by wires that pass directly through the soft tissues of the face is a most practical addition to the methods which are applicable to the treatment of fractures of the face (Fig 102)

bones corrected Occasionally these bones may need to be fixed by open reduction before the occlusion is re-established and the face is restored to normal position If the mandible is fractured and displaced it is

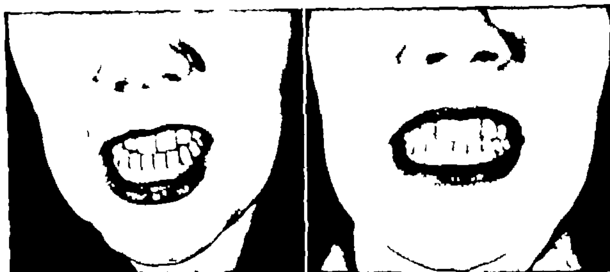


Fig 101—**Left** malocclusion of the teeth associated with a transverse fracture of the middle third of the face The malocclusion was overlooked. **Right** restoration of occlusion which required refracture of the maxilla through the floor of the nose and antrum support of the alveolar arch with wires through the face anchored to the orbital rim and wiring of the upper and lower teeth in occlusion for about 6 weeks

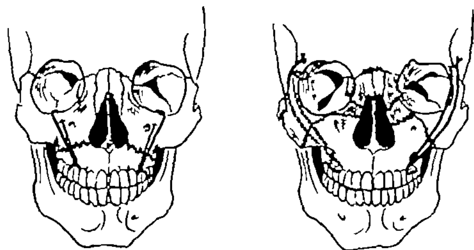


Fig 102.—Direct wiring of the floating maxilla to the orbital rim **Left** the wire is fixed below the zygomaticofrontal suture line if the zygoma is stable **Right** *if the zygoma is unstable* the wire for fixation must be attached to the stable zygomatic processes of the frontal bones in the upper lateral orbital rim The wires are passed through the soft tissues of the face either anteriorly over to the malar prominence or posteriorly through the temporal fossa

The goal of treatment is to support the sagging face and to restore normal occlusion (Fig 103) The bones of the face must be mobilized and obvious displacements of the zygoma lacrimal and other facial

desirable to reduce and fix it first, because it serves as a valuable guide in repositioning the fractured maxillary complex. The use of internal wire fixation for support of the upper alveolar process and the sagging



Fig 103 —Severe fracture of the face and jaw from an automobile accident **Top views** the fracture of the face traverses the antrum with complete separation of the floor and alveolar processes which are displaced downward and backward The right malar bone is also displaced downward and backward and there is a fracture of the mandible at the right mental foramen **Bottom views** the facial fracture was reduced and supported by wires passed through the facial tissues looped through holes in the zygomatic process of the frontal bone and anchored to molar teeth in the upper alveolar arch The displaced malar bone was elevated and then held in place with a gauze pack in the antrum. Finally the malocclusion due both to the displaced fracture of the face and to the mandibular fracture was reduced and fixed by wiring the upper and lower teeth together

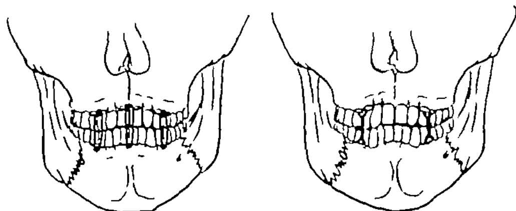


Fig 104 —Methods of direct fixation of the teeth by wires Occlusion may be established by elastic traction through hooks or buttons (left) or by direct wiring of opposing teeth to each other (right)



Fig 105 —Left view bilateral fracture of mandible at the angles A molar tooth retained in the posterior fragment on the left side of the face prevents over riding by the ramus Open reduction and wiring were necessary on the right side only (right view) The jaw was immobilized for 8 weeks by fixing the teeth in occlusion.

framework of the face has meant that materials available in every well-organized operating room have replaced all manner of complex splints inefficient head caps and unstable and consequently painful guy wires The intact dental arch is anchored directly to the stable orbital rims or the zygomatic arches by these wires through the substance of the cheeks Small incisions will suffice for exposure of either or both orbital rims or zygomatic arches and for making small drill holes If the upper jaw is edentulous the wire may be attached to an intact dental plate or to the bony alveolus directly When this method is used immediate and accurate reduction and fixation are possible and occlusion can be re established promptly no other splinting



Fig 103 —Severe fracture of the face and jaw from an automobile accident Top views the fracture of the face traverses the antrum with complete separation of the floor and alveolar processes which are displaced downward and backward The right malar bone is also displaced downward and backward and there is a fracture of the mandible at the right mental foramen Bottom views the facial fracture was reduced and supported by wires passed through the facial tissues looped through holes in the zygomatic process of the frontal bone and anchored to molar teeth in the upper alveolar arch. The displaced malar bone was elevated and then held in place with a gauze pack in the antrum Finally the malocclusion due both to the displaced fracture of the face and to the mandibular fracture was reduced and fixed by wiring the upper and lower teeth together

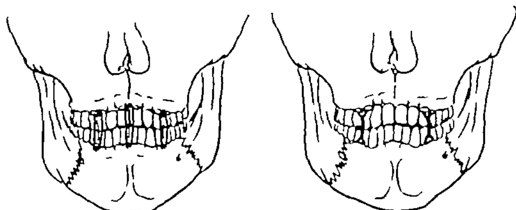


Fig. 104 —Methods of direct fixation of the teeth by wires Occlusion may be established by elastic traction through hooks or buttons (left) or by direct wiring of opposing teeth to each other (right)



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will be required Support for the upper jaw and splinting of the teeth in occlusion must be continued for 6–8 weeks The wires passing through the cheek may be removed at that time or left in place indefinitely

Fracture of the alveolar process may involve any segment of the alveolar arch Either fixation by wiring to the adjacent undisplaced teeth or interdental fixation may be employed Rarely is the displacement so severe that the blood supply to the bones and retained teeth is destroyed

Fractures of the Mandible

Most mandibular fractures can be reduced and fixed in position by wiring the upper and lower teeth in occlusion (Fig 104) Wires around two pairs of opposing molar teeth on each side of the upper and lower jaws may be twisted together to form four buttons to which elastic bands can be attached or the wires on the opposing teeth may be attached to each other to furnish more absolute fixation The latter method is undesirable if a general anesthetic has been used, because the mouth cannot be easily emptied of vomitus thus increasing the chance of aspiration Final wiring of the teeth may have to be delayed until the patient is fully conscious

When teeth are either inadequate or absent in any or all of the fragments the problem is more complicated but still lends itself to surgical management. For example the posterior fragment in fractures of the mandible at the angle is often edentulous because the fracture line is behind the last molar tooth The ramus is pulled upward and inward at the temporal masseter and internal pterygoid muscles If because of the direction of the fracture the posterior fragment does not lock against the anterior fragment (Fig 105) the fragments must



Fig 106 —Left view fracture of the neck of the mandibular condyle in a child Although many of these fractures are best treated by splinting the jaw only the displacement in this patient was so gross that open reduction through a small incision anterior to the ear was carried out (right view) No direct fixation of the fragment was necessary but the teeth were wired in occlusion for several weeks

be held reduced either by direct wire fixation after exposure through an external incision or by transfixion with an internal wire pin Other methods such as elastic traction to a head cap external skeletal fixation (Stader) and an intraoral dental splint, are very complex and require frequent adjustment A totally edentulous mandible may be wired directly or may be splinted to the patient s dental plate by the passing of circumferential wires around each fragment The anterior fragment must always be supported against the downward pull of the geniohyoid genioglossi, digastric and mylohyoid muscles Occlusion will be restored if the lower plate is attached to the upper teeth or to the upper dental plate which must be supported against the roof of the mouth by wire fixation Fractures of the symphysis may be unstable laterally and require direct wiring of the lower border or transfixing with an internal wire pin The management of a fracture of one or both condyles is still a controversial matter Some authors advocate open reduction of most of these fractures (Fig 106) Others consider this meddlesome surgery because exposure and fixation of the tiny condylar fragment is quite difficult With rare exceptions an excellent functional result can be expected if the mandible is splinted in normal occlusion until the condyle has united

Fractures of the mandible with loss of bony substances require the accurate maintenance of dental occlusion Early restoration of continuity of the bone must be planned as soon as soft-tissue healing permits Rib or iliac bone grafts may be used and will act as an effective splint for any nonimmobilized or edentulous fragments.



Fig 107 —Fracture of the right mandible at the angle compound into the mouth. The posterior fragment of the mandible cannot ride forward by pull of the masseter and temporal muscles because the tooth which lies in the fracture line obstructs this motion It is safe to leave the tooth in place temporarily until the fragments unite sufficiently to prevent over riding It should then be extracted Were the fracture behind the molar tooth direct fixation of the posterior fragment would probably be necessary to prevent over riding. In either situation wiring of the opposing upper and lower teeth in occlusion for 6–8 weeks is essential

Since practically all mandibular fractures are compounded into the mouth the risk of infection is always present. For this reason nonvital loose teeth in the fracture line should be removed unless they are useful temporarily as a splint (Fig 107) External drainage of the fracture line may be desirable until the mucosa is healed

In the evaluation of the healing of mandibular fractures the x ray film may fail to reveal any callus A more reliable *test* is clinical examination of the bone union Fixation for 6–8 weeks is usual in uncomplicated mandibular fractures

MANAGEMENT OF THE SOFT PARTS

All fresh lacerations of the face should be repaired promptly Only by early accurate closure of skin and mucous membrane can scarring and deformity be reduced. The healing power of the face is excellent, and

Great care and patience are necessar identifying and replacing the jagged e of torn and avulsed skin of the eyelids n and mouth especially if the laceration tends through both surfaces of the part v a full-thickness separation of the ed The fitting together of obscurely mispla flaps may require several attempts bel



Fig 108 —Left multiple severe lacerations of face eyelids and cheek with avulsion of p tions of the scalp the result of an automobile collision After washing away the clotted bloo trimming the hair and removing fragments of glass in the wounds, the pattern of the lacer tions became clear and primary suture was carried out. Fine (5-0) catgut was used for closu of the deep tissues and the dermis Approximation of the skin edges was so accurate that on a minimum number of skin sutures were necessary Right final result, 1 year later

the resistance to infection high Success depends on the observation of certain precautions the most important of which is that no additional damage be done These precautions include avoidance of unnecessary debridement of wide sutures which will leave stitch marks and of excessive tension especially on flaps of skin with precarious blood supply All wounds must be thoroughly cleansed foreign material removed and hematomas evacuated Layer closure of the subcutaneous tissues as well as of the skin must be done with very fine suture material. All skin sutures should be removed within 48–72 hours

the correct position is obtained Obvio points of approximation such as the ve milion border the eyelid margin or th alar margin are useful as starting poin for suturing (Fig 108)

The number of sutures on the inner su face of the mouth nose or eyelid should b no more than needed to obtain accurate ap position of the mucosa. Puncture wound especially of the lips are best left un sutured free drainage is thus maintained and the likelihood of infection lessened Small lacerations on the face can some times be approximated by adhesive support alone

Skin losses can be replaced by skin grafts if the deep tissues are not severely damaged In extensive full thickness losses of the cheek nose and (rarely) the eyelid mucosa and skin may be approximated to close the raw surface in anticipation of later repair

Suture of branches of the seventh facial nerve is impractical because the fibers are tiny and identification may be impossible

the scar or thickening of the scar where it crosses normal folds In anticipation of these deformities some surgeons recommend primary small zigzag flaps to avoid straight line suturing of these lacerations (Fig 109)

In the management of the primary wound it must be anticipated that secondary revision of the soft tissues may be necessary in many severe facial injuries



Fig 109 —Left thickened scar following primary suture of a laceration across a crease below the lip This type of scar is corrected by a rotation of local flaps (Z-plasty) Some surgeons prefer to carry out the Z-plasty at the time of closure of the primary wound in anticipation of the deformity Right typical trap-door flap deformity This deformity is caused by the contraction of the scar which, because of its U shape constricts and thickens the skin within the circle of the scar The deformity is correctable only by multistage thinning of the flap by opening the marginal scar

If the larger trunks near the angle of the jaw can be identified suture is indicated Primary repair of a lacerated Stensen duct should be considered in injuries of the cheek A tiny probe or piece of suture material may be used as an internal splint. The tissues of the cheek are often so badly injured that repair may have to be postponed

Among the most troublesome of all the lacerations of the face are the so-called "trap-door flaps" caused by U-shaped lacerations in the face In these U shaped lacerations and in curved lacerations crossing the cheek the body of the mandible or elsewhere on the nose or face the normal contraction of the healing scar tissue produces a fullness of the skin on the concave side of

Nothing should be done to make the later procedures more difficult.

DRESSINGS

A firm resilient pressure dressing is essential after the definitive primary reduction of facial fractures and after suture of facial wounds It is also useful before treatment if there are to be unavoidable delays Oozing of blood from the damaged tissues and the further development of edema are best controlled by such a dressing Edema which develops rapidly after injury and manipulation of the tissues may persist for many weeks or months unless it is reduced to a minimum by the prompt application of a firm dressing.

POSTOPERATIVE CARE

Chemotherapy antibiotics and other agents are indicated in all severe facial injuries The choice will depend on the condition of the mouth and tissues the character of the injury and the surgeon s preference *Tetanus prophylaxis must not be over looked* Gas gangrene in the face is almost unheard of however The usual supportive measures including fluid by vein and transfusions should be continued until the patient is able to take sufficient fluid and food by mouth A high-caloric high vitamin liquid diet must be available for all patients with interdental wiring

In all patients with open fractures into the mouth or nose *cleanliness is essential* Irrigations mechanical removal of debris and mouth washes are useful. Patients with interdental wiring may have real difficulty in keeping the mouth clean unless frequent irrigations are given. Mechanical cleansing of the teeth with a short-bristle toothbrush is desirable

Dressings should be replaced after the skin sutures are removed on the second or third day The tissues in severe injuries need the support of a dressing for about a week. The dressing serves also as a splint for bony fragments that do not solidify before the seventh to the tenth day

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14  Craniocerebral Injuries

IN THE COURSE of evolution the human animal has become increasingly vulnerable to trauma to his skull and brain In the development of the cerebral hemispheres the head has become larger the skull relatively thinner and the increasing mass of the brain has added to its momentum on impact These factors combined with the accelerated tempo of the mechanical age and the increasing destructiveness of modern high velocity missiles have resulted in a steadily mounting incidence of craniocerebral injuries in peacetime as well as in war According to Lewin the total number of head injuries requiring inpatient treatment in Great Britain had risen to 35 000 annually in 1954

The purpose of this chapter is to stress the simple practical steps that can be taken by the general surgeon in the care of these emergencies and to outline briefly the more unusual situations and complications that are best left for the neurosurgical specialist. It should be borne in mind that patients with craniocerebral injuries can be safely transported either by motor ambulance or by air to centers where specially trained medical personnel are available provided that bleeding has been controlled and provision made for adequate respiratory exchange If these lethal factors are eliminated there is no tendency for shock to develop With adequate use of antibiotics infection even in severe open fractures is not likely to set in during the first few hours if hair and gross dirt are cleared from the edges of the wound and a sterile dressing applied With over 500 certified neurosurgeons in the United States and an adequate number in the Armed Forces major intracranial procedures need rarely be undertaken by the general surgeon.

MECHANISM OF HEAD INJURY

When the moving head strikes a fixed object or when the stationary head is hit by a moving object injury may occur to the scalp skull or brain Cerebral contusion may be lethal regardless of whether a fracture is present or not Fractures of the skull tend to follow a definite pattern according to the mechanical lines of stress and the thickness of bone as has been described by Gurdjian and his co-workers A linear or comminuted fracture even a relatively extensive one is not necessarily accompanied by serious damage to the underlying brain On the other hand relatively innocent appearing fractures in certain regions of the skull may be dangerous For example simple appearing linear fractures which cross the groove of the middle meningeal artery or one of its branches in adults and older people are likely to tear the vessel and lead to fulminating epidural



Fig 110 —Roentgenograms of linear and depressed fractures which led to serious complications A, linear fracture crossing groove of middle meningeal artery which was torn causing an extradural hematoma B linear fracture which entered ring of foramen magnum The patient although having extensive contrecoup injuries (see in Fig 113) appeared at first to have suffered only a brief concussion On admission she was alert and without abnormal neurological signs but she died suddenly of respiratory failure from a cerebellar pressure cone C, depressed temporal fracture following fall from a bicycle (Note the characteristic lines of increased density where the edges of bone overlap) This young girl had an immediate concussion followed by a lucid interval and then severe convulsions. This suggested bleeding from a torn middle meningeal artery but the artery and the dura were intact. Seizures ceased as soon as the indriven fragments of skull were elevated and recovery was uneventful



Fig 111 —X-rays of comminuted fractures involving frontal sinus A, extensive comminution with fracture line crossing frontal sinus B postoperative films of same patient after debridement with removal of loosened avascular bits of bone and mucosa of frontal sinus The remaining fragments are held in position by wire sutures passed through drill holes. C a similar fracture in which the surgeon did not remove the loose avascular bits of bone and mucosa of frontal sinus This patient developed a fatal abscess deep in the frontal lobe outlined by in jected Thorotrast.

hemorrhage (Fig 110 *A*) Other fractures which cross the major venous sinuses in the dura may also result in serious bleed ing Basilar fractures which enter the fora men magnum may cause cerebellar swell ing with compression of the medulla and sudden respiratory failure (Figs 110 *B* and 113 *below*) Others often not demon strated in the x ray may be followed by leakage of cerebrospinal fluid from the nose and ear and thereby open up pathways of infection to the brain Fracture lines may also cross the bony foramina of exit of cranial nerves and thereby lead to loss of smell, sight hearing or facial paralysis If they cross the cavernous sinus and the si

phon of the internal carotid artery is torn an arteriovenous fistula will result, with a bruit synchronous with the heartbeat and development of a pulsating exophthalmos

Depressed fractures may result in severe contusion of the underlying brain and subsequent epilepsy if the indriven fragments are not elevated and the devitalized brain removed (Fig 110 *C*) This is also true of open fractures either from penetrating wounds or depressed fragments when the dura is torn but here there is the added risk of subsequent infection with meningitis or brain abscess (Fig 111 *C*) The surgeon who deals with even an innocent looking laceration of the scalp must bear in mind that there may be an underlying injury to the skull and dura This is particularly likely to occur in minute wounds from high-explosive bombs Neglecting to diagnose these and to debride and treat properly the compound injury cost the lives of many Britons in the early days of the German air raids Neglect of even a simple scalp laceration without any underlying fracture may lead to chronic infection with complicating osteomyelitis abscess of the brain and ultimate death

Damage to the brain itself may be severe and even lethal without there being any evidence of cranial fracture In experiments on monkeys Denny Brown and Russell showed that brief loss of consciousness (concussion) is likely to occur either on sudden acceleration or deceleration of the head at a velocity of about 28 feet per second In man with his larger brain concussion can occur even on falling from a sitting position wher the head strikes a hard floor A fall of only 4¼ feet cannot result in a velocity of greater than 17 feet per second and even slower rates than this may lead to transitory loss of consciousness

In simple concussion, loss of consciousness is brief and there is no evidence of lasting damage to the brain Its mechanism is poorly understood but the mental black out is accompanied by a suppression of nerve impulses which are constantly active in the state of wakefulness Electroencephalographic studies have shown that in the conscious state there is a constant transmission of electrical activity between different areas of the cortex and the thalamus and reticular formation in the midbrain In the comatose state as well as during sleep and anesthesia, these rapid long-circuiting mechanisms are lost and only slow wave activity remains

After concussion there is brief electrical silence then slow waves followed by recovery of normal activity as consciousness returns With diffuse contusion of the brain, where swelling occurs widely throughout the cortex or in the central activating centers of the thalamus and mesencephalic reticular formation, abnormalities in EEG activity and coma persist. Consciousness may be lost permanently with signs of decerebration. This may result either from sudden posterior displacement of the brain when the mesencephalon strikes against the rigid edge of the tentorium or subsequently when the brain swells and the mid brain is compressed by herniation of the temporal lobe through the tentorial notch (Fig 112) In these circumstances the victim may succumb rapidly or may continue to live in a vegetative state for months without ever becoming aware of his surroundings Three of our 226 patients have remained in a state of permanent decerebration from this mechanism

Certain areas of the brain are particularly likely to incur damage In high-speed movies of monkeys with the cranial convexity removed and replaced by transparent lucite plates Pudenz and Shelden were able to show the shift of the brain which takes place in the axis by a forceful blow against the forehead or occiput. When this occurs certain characteristic areas suffer the most intense injury The most severe contusion or laceration of the brain is often found on the side opposite the blow (contrecoup) (Fig 112 *A* and *B*) After a blow on the occiput the contusion or laceration may be most severe on the under surface of the frontal lobes where these come in contact with the irregular surface of the orbital plates (Fig 113 *above*) or at the tips of the temporal lobes which strike the sharp edge

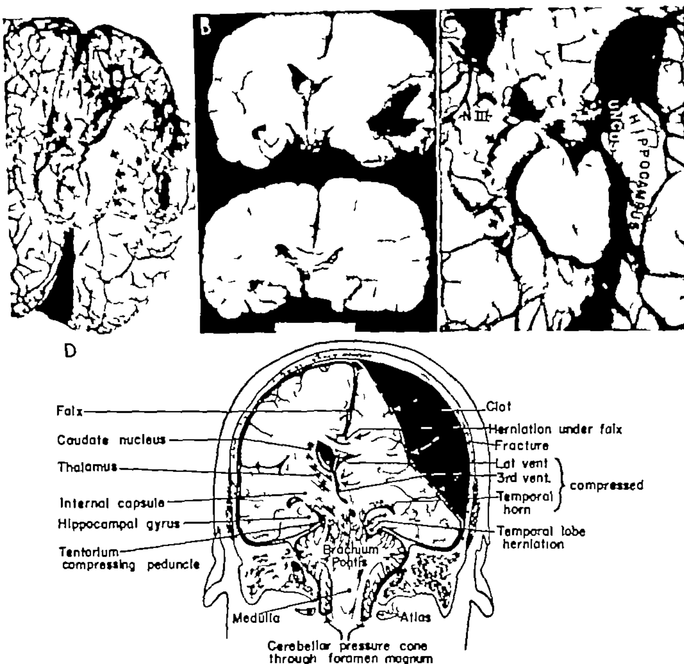


Fig 112.—Mechanism of pressure-cone formation. Top views lesions found at postmortem in two fatal cases A, severe contusion and laceration of cortex on left side of brain following a blow on right side of head. The herniated inferior medial edge of the left temporal lobe is marked by arrows and a hemorrhage is present in the compressed midbrain B the brain cut in cross-section to show extensive swelling of the left hemisphere and a large subcortical clot C right uncal herniation (at left side marked by three arrows) The oculomotor nerve can be seen crossing under the rostral end of the hernia its compression had caused dilatation of pu pil There is also a small hemorrhage in the compressed side of brain stem. The hippocampal gyrus and uncus on the opposite side are normal D a coronal cross-section through the mid dle of the head illustrating herniations beneath the falx through the tentorial notch and fora men magnum produced by a large extradural hematoma

of the sphenoidal ridge Other vulnerable areas are th' tips of the frontal or occipital lobes and the midbrain when it impinges ventrally against the basisphenoid or dorsally against the sharp inelastic edge of the tentorium Occipital injuries particularly when there are fractures into the foramen magnum may lead to swelling of the cerebellum and force the cerebellar tonsils down into the bony outlet of the skull This shifting may lead to medullary compression with sudden respiratory failure (Fig 113 below)



Fig 113 —Contrecoup injuries in patient who had a linear occipital fracture from an automobile accident (see Fig 110 B for x ray) Top hemorrhage in frontal lobes Bottom herniation of tonsils with added hemorrhage in right cerebellar hemisphere Death resulted from compression of medulla and respiratory center

Another cause of critical cerebral compression is intracranial bleeding This may occur rapidly if the middle meningeal or some other artery on the outer surface of the dura (Fig 114 A and B) is torn by a fracture running across its groove in the inner table of the skull Slower venous bleeding may develop after much milder injuries without any fracture when one of the bridging veins running from the medial surface of a hemisphere or to other parts of the dura (Fig 114 A and C) is torn as the brain shifts on impact Venous bleeding of this sort commonly occurs between the dura and the arachnoid where the blood cannot

be absorbed It is under such low pressure that it commonly stops by tamponade with out at first producing any symptoms al though a thin film of blood may cover the entire surface of one or both hemispheres the membrane draws in fluid from the con tiguous subarachnoid space As a result the clot expands and there is gradual compression of the brain Increasing intracranial pressure and displacement of the brain

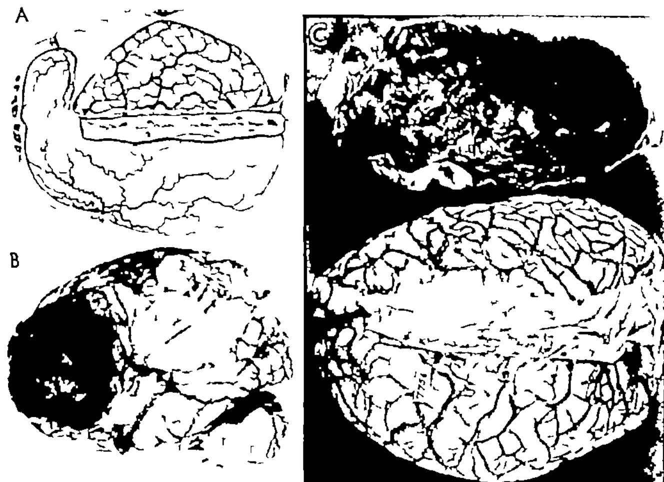


Fig 114 —Mechanism of epi and subdural hemorrhage A blood vessels of dura and cerebral cortex The longitudinal sinus has been opened to show orifices of cerebral veins which run across to the hemisphere The distribution of the middle meningeal artery on the outer surface of the dura is shown in the lower half of the drawing. (Modified from Deaver J B *Surgical Anatomy of the Human Body* [New York Blakiston Division McGraw Hill Book Company Inc 1926]) B epidural hemorrhage in a boy who was struck in the right frontal area by a pitched baseball After a brief loss of consciousness there was a lucid interval in which he walked home and went to bed He was later found in deep coma and brought to the hospital moribund (Specimen was obtained from the Medical Examiner of Boston City Hospital Dr Timothy Leary) C subdural hematoma (unsuspected) found at a medical postmortem in a man who had been treated for measles

Gradually a membrane is formed by fibroblasts covering both the inner and outer surfaces of the hematoma This membrane is permeable to water and electrolytes but not to larger protein molecules Therefore when the blood proteins break down to bili rubin, biliverdin and other smaller molecules the rising osmotic pressure within with final herniation of the inner edge of the temporal lobe ultimately lead to serious symptoms and if the clot is not diagnosed and evacuated in time to a fatal outcome

Bleeding between the dura and arach noid may also occur with serious symptoms within the first few hours or days after a blow on the head The mechanism of these

acute subdural hematomas is poorly understood since there is no time for a membrane to form and for the clot to expand by imbibition of water The venous pressure is much too low to cause cerebral compression. This complication probably results from severe trauma with laceration of the brain and with blood entering the subdural space through a tear in the arachnoid

Subarachnoid bleeding results from cerebral laceration but by itself is less serious because blood can be absorbed from this region Massive intracerebral bleeding is rare with closed injuries of the brain but small hemorrhages in the brain stem leading to decerebration and prolonged coma are unfortunately all too common, as pointed out above Multiple punctate hemorrhages may also be found widely scattered throughout the hemispheres after severe contusion or in the chronic stage of post traumatic deterioration ("punch drunk") seen in prize fighters and others who have suffered repeated sublethal blows on the head.

The seriousness of penetrating wounds depends on the size and velocity of the missile as well as on its course Modern high velocity bullets produce an expansile wave of pressure as they pass through tissue This pressure wave is capable of destroying brain far beyond the tract of the bullet On the other hand a low velocity 22-caliber bullet can traverse the hemisphere with little risk of sepsis and even without producing loss of consciousness provided that it does not traverse the basal ganglia or brain stem Serious hemorrhage is a rare complication if no major artery or dural sinus is torn Larger more slowly moving shell fragments and other objects penetrating the skull produce local damage to the cortex and a greater risk of infection from indriven fragments of bone and hair

In a series of 226 severe craniocerebral injuries admitted to the wards of the Massachusetts General Hospital 40 per cent of the injuries resulted from falls of various sorts 25 per cent from traffic accidents 17 per cent from blows on the head 10 per cent from penetrating projectile wounds and 8 per cent from trauma of unknown origin Thirteen per cent of these injuries occurred as a result of acute or chronic alcoholism

FIRST AID AND TRANSPORT TO HOSPITAL

As stated before the first essential in caring for an unconscious individual with a head injury is to secure and maintain an adequate airway This can usually be accomplished by rolling the patient onto his abdomen or side In either position the tongue drops forward secretions drain from the corner of the mouth and the danger of inhalation of vomitus is greatly reduced Adequate respiratory exchange is a matter of primary importance because anoxia leads to further swelling of the brain and any increase in carbon dioxide causes dilatation and engorgement of its blood vessels

If there is active bleeding from a scalp laceration, this is easily controlled by pressure and will soon stop Any scalp wound should be covered with a thick sterile dressing. Nothing can be done on the spot about deep bleeding from a penetrating cerebral wound but such bleeding is rarely severe unless a major artery has been severed The earliest possible transport to a hospital is necessary to deal with profuse intracranial bleeding.

In addition to examining for possibl thoracic abdominal or bony injuries it i important to remember that there may be concomitant trauma to the spinal column Vertebral fractures and dislocations can rarely be diagnosed unless there is coincident injury to the spinal cord This may be produced when an individual is struck on the head and there is violent displacement of the neck. An examination should always be made to see if there is normal thoracic breathing and if the victim can be made to move his upper and lower extremities (see Chapter 15 on Injuries to Spinal Cord and Cauda Equina)

Narcotics should never be given to any individual with a serious cerebral injury

since opiates are respiratory-depressant drugs and cause swelling of the brain Semistupor and restlessness can be controlled safely and better by paraldehyde The drug *can be administered in doses of* 1–2 cc intravenously or 4 cc intramuscularly when rapid absorption is necessary *when in less haste an initial similar dose* can be given per rectum repeating as necessary in smaller amounts

Unless there has been extensive blood loss or other serious injuries there should be no shock and the sufferer from cerebral trauma can be safely transported for considerable distance if coma is not progressively deepening and the factors stressed above have been attended to It is usually better to move the patient who is not obviously in extremis a longer distance to a hospital accustomed to neurosurgical problems than to deposit him in a nearer one with inadequate facilities and wait for a consultant to make the journey Not only does the latter procedure take longer but without experienced nurses anesthetists and other necessary facilities the neurosurgeon may find on his arrival that it is extremely difficult to carry out his intricate procedures as well as to supervise the critical situation afterward

EXAMINATION AND EVALUATION OF CEREBRAL INJURIES

In examining a patient with a head injury the surgeon should always make a careful search for other injuries Aside from injury to the facial bones spinal cord or damage *to other structures* which are dealt with in separate chapters of this volume the matter of first importance is to evaluate the degree of damage to the brain and its coverings Bleeding from a lacerated scalp will probably have ceased by the time the injured individual is brought to the emergency ward Occasionally a large vessel in the galea will need to be clamped and sutured

Inspection of the head will often reveal the presence of a large open or depressed fracture although small breaks under a lacerated scalp will require x ray or palpation of the bone at the time of debridement and suture of the scalp When there is subgaleal bleeding without a laceration a crater *is often felt in the center of the* clot suggesting a depressed fracture The true situation here will be clarified by x ray

The first priority needs of the severely injured patient are to start transfusion of blood if there is shock from blood loss or other injuries to order intravenous or intramuscular antibiotics if there is a contaminated wound and to rule out certain critical possibilities regarding the intracranial injury The most important evidence in this respect is the level of consciousness and the respiration In severe injuries with swelling of the brain or with pressure coning from hemorrhage there is usually deepening coma Unilateral dilation of the pupil may develop from pressure of the herniating *temporal lobe against the oculomotor* nerve With herniation of the cerebellar tonsils respiratory failure or Cheyne-Stokes respiration with increasing periods of apnea, may develop These are warning signs of imminent danger to life The Cushing triad of rising blood pressure with slowing pulse and respiration has long been regarded as a sign of increasing intracranial pressure but on many occasions these vital signs do not alter in this way Inhalation of oxygen and intravenous administration of hypertonic solution (100 cc of 50 per cent sucrose) may help over a critical period if it appears that this dangerous situation can be corrected by evacuation of a clot

If the patient is *conscious* there is *no* great urgency Injuries to the scalp cranium and local areas of the brain can be dealt with at leisure Striking drops in blood pressure with peripheral circulatory failure in a conscious alert individual are not likely to be due to the head injury When these occur occult hemorrhage elsewhere should be looked for On the other hand *rapidly* deepening coma particularly when there is evidence of contusion and fracture in the temporal region is the danger signal of a rapidly expanding intracranial clot

acute subdural hematomas is poorly under stood, since there is no time for a mem brane to form and for the clot to expand by imbibition of water The venous pressure is much too low to cause cerebral compression. This complication probably results *from severe trauma with laceration of the* brain and with blood entering the subdural space through a tear in the arachnoid

Subarachnoid bleeding results from cer ebral laceration but by itself is less seri ous because blood can be absorbed from this region. Massive intracerebral bleeding is rare with closed injuries of the brain but small hemorrhages in the brain stem lead ing to decerebration and prolonged coma are unfortunately all too common, as pointed out above Multiple punctate hem orrhages may also be found widely scattered throughout the hemispheres after severe contusion or in the chronic stage of post traumatic deterioration ("punch drunk") seen in prize fighters and others who have suffered repeated sublethal blows on the head.

The seriousness of penetrating wounds depends on the size and velocity of the missile as well as on its course. Modern high velocity bullets produce an expansile wave of pressure as they pass through tissue This pressure wave is capable of destroying brain far beyond the tract of the bullet On the other hand, a low velocity .22-caliber bullet can traverse the hemisphere with little risk of sepsis and even without producing loss of consciousness provided that it does not traverse the basal ganglia or brain stem Serious hemorrhage is a rare complication if no major artery or dural sinus is torn Larger more slowly moving shell fragments and other objects penetrat ing the skull produce local damage to the cortex and a greater risk of infection from indriven fragments of bone and hair

In a series of 226 severe craniocerebral injuries admitted to the wards of the Massa chusetts General Hospital 40 per cent of the injuries resulted from falls of various sorts 25 per cent from traffic accidents 17 per cent from blows on the head 10 per cent from penetrating projectile wounds and 8 per cent from trauma of unknown origin. Thirteen per cent of these injuries occurred as a result of acute or chronic alcoholism

FIRST AID AND TRANSPORT TO HOSPITAL

As stated before the first essential in caring for an unconscious individual with a head injury is to secure and maintain an adequate airway This can usually be ac complished by rolling the patient onto his abdomen or side In either position the tongue drops forward secretions drain from the corner of the mouth and the danger of inhalation of vomitus is greatly reduced Adequate respiratory exchange is a matter of primary importance because anoxia leads to further swelling of the brain and any increase in carbon dioxide causes dilatation and engorgement of its blood vessels

If there is active bleeding from a scalp laceration this is easily controlled by pressure and will soon stop Any scalp wound should be covered with a thick sterile dressing Nothing can be done on the spot about deep bleeding from a penetrating cerebral wound but such bleeding is rarely severe unless a major artery has been severed. The earliest possible transport to a hospital is necessary to deal with profuse intracranial bleeding

In addition to examining for possible thoracic abdominal or bony injuries it is important to remember that there may be concomitant trauma to the spinal column. Vertebral fractures and dislocations can rarely be diagnosed unless there is coinci dent injury to the spinal cord This may be produced when an individual is struck on the head and there is violent displacement of the neck An examination should always be made to see if there is normal thoracic breathing and if the victim can be made to move his upper and lower extremities (see Chapter 15 on Injuries to Spinal Cord and Cauda Equina)

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Epidural hemorrhage is likely to follow a forceful blow on the side of the head by a pitched baseball or some other object that cracks the thin temporal squama and tears the middle meningeal artery in its bony groove The force of impact need not be sufficient to contuse the entire brain and so loss of consciousness may be brief and often there is an ensuing lucid interval. Soon afterward however the victim complains of increasing headache and becomes somnolent he is likely to vomit and may develop contralateral neurological signs or convulsive seizures The level of consciousness declines. In the terminal stage of compression the pupil on the involved side may show enlargement and fixation to light from pressure on the oculomotor nerve by the herniating portion of the temporal lobe This sign is not invariably present and the dilated fixed pupil is not necessarily found on the side of the clot. During the progressive impaction of the uncus and hippocampus (medial and inferior portion of the temporal lobe) in the *tentorial notch there may also* be involvement of one or both pyramidal tracts This is caused by the advancing hernia on one side and the pressure against the rigid edge *of the tentorium* on the other This critical situation is evidenced by the appearance of unilateral or bilateral extensor plantar responses and extensor spasms of the arms and legs (decerebrate rigidity) Another complication of a fatal herniation of the temporal lobe usually found on postmortem examination is compression of the posterior cerebral artery with infarction of the occipital lobe With the characteristic picture of secondary loss of consciousness and evidence of midbrain compression there is no difficulty in diagnosis but when the patient is intoxicated or remains unconscious following the initial injury the doctor must be alert to make the diagnosis of complicating hemorrhage

The degree of cerebral trauma after a diffuse contusion of the brain is best estimated by the duration of retrograde and post traumatic amnesia or coma When the cerebral trauma is diffuse and severe memory for events preceding the injury is lost for a period of minutes or hours The period of *confusion or coma after an injury may* extend over hours days or even for an indefinite period

A neurological examination is difficult to make in deep coma *Inspection* of the pupils is of particular importance With temporal pressure coming from cerebral edema or intracranial hemorrhage the pupil enlarges because its constrictor fibers in the vulnerable oculomotor nerve are paralyzed Symmetrically constricted or dilated pupils that do not respond to light may also indicate brain-stem compression. Even more ominous signs of injury to this vital area are extensor rigidity of the limbs with periodic episodes of intense extension and opisthotonus (decerebrate seizures) These phenomena, together with bilateral Babinski extensor plantar responses are evidence of decerebration at the midbrain level and warning signs of early death or long lasting coma

Certain deviations of the eyes suggest injury *to areas of the brain controlling* ocular movements Lack of convergence may be seen in coma continued deviation of both eyes to the right or left most often indicates contusion with paralysis *of the* ipsilateral cortical area for adversive eye turning in the premotor cortex. The eyes are therefore unable to turn to the opposite direction and deviate *toward the side of* the injury Loss of movement of the lower face arm or leg on one side suggests injury to the opposite precentral gyrus which contains the motor strip Sometimes when this area is irritated by trauma there will be Jacksonian seizures with turning of the head and eyes to the opposite side and convulsive movements of the contralateral extremities. Increase in deep-tendon reflexes may be seen on the paralyzed side together with an extensor plantar response of the big toe As mentioned above bilateral Babinski responses on stroking the soles are an ominous sign because they indicate injury to both sides of the brain or more specifically damage to the peduncles in the midbrain

When the patient is conscious neurological examination can give much more exact evidence of brain injury Some degree of speech defect (aphasia) is likely to follow cortical damage in the dominant hemisphere Characteristic field defects occur after injuries to the occipital visual areas the optic radiation in the temporal lobe optic tracts or chiasm Even bilateral loss of vision has been known to follow severe contusion of both occipital lobes In this condition the unfortunate victim loses even his perception of light although the pupils constrict because the reflex arc runs down into the midbrain Evidence of cerebellar damage is not often seen When present this consists of in-co-ordination of synchronous movements of the extremities in the absence of paralysis with past pointing and poor performance of the finger to-nose and heel-to-shin tests on the side of the injury Nystagmus is likely to occur in damage to the cerebellum and its connections with the brain stem

Certain cranial nerves are frequently injured—the olfactory particularly with loss of smell on the side where the nerve is injured Smell may be lost on both sides when the brain shifts backward and the nerves are avulsed. This leads to serious impairment of taste as well. Fractures crossing the optic foramen often cause blindness with loss of the direct pupillary response to light. Any one or all of the nerves to the muscles that move the eyes may be injured with consequent diplopia With injury to the third (oculomotor) nerve the eye is closed (ptosis) the pupil is dilated and owing to the unopposed action of the lateral rectus the eye is deviated laterally With injury to the fourth (trochlear) nerve the eye is in the primary position but the head is tilted to the homolateral shoulder thus avoiding the diplopia consequent to extorsion of the eye With injury to the sixth (abducens) nerve the eye is directed inward owing to the unopposed action of the medial rectus With paralysis of all the ocular motor nerves the eye is closed the pupil is dilated and the eye is immobile in the primary position. The facial nerve is often injured by fractures crossing its bony canal in the petrous portion of the temporal bone When this occurs the eyelids cannot be closed or any of the facial muscles moved * In addition there is loss of taste in the anterior portion of the tongue Hearing is also often lost in fractures of the petrous bones and briefly impaired if there is hemorrhage into the middle ear Injuries to the other cranial nerves (V IX X, XI and XII) are rarely seen The fifth (trigeminus) cranial nerve carries sensation to the face forehead and anterior portion of the scalp to the oral mucosa as far back as the tonsils and to the anterior two thirds of the tongue It also has a small motor branch to the jaw muscles injury to which leads to deviation of the lower jaw to the paralyzed side The ninth (glossopharyngeal) cranial nerve gives the sensory supply to the posterior third of the tongue and upper pharynx Damage to the tenth (vagus) cranial nerve results in anesthesia of the lower pharynx and larynx with a hoarse voice due to paralysis of the vocal cord. Injuries to the spinal accessory nerve produce paralysis of the sternomastoid and trapezius muscles with shoulder drop Unilateral paralysis of the tongue with deviation to the involved side on protrusion follows injury to the twelfth (hypoglossal) nerve

In the conscious individual it is much easier to detect minor impairment of cortical motor function. Also it is possible to examine for damage in the postcentral sensory cortex by testing light touch two-point discrimination position sense and perception of objects placed in the hand or figures drawn on the skin of the fingers and toes

By careful neurological examination it is possible to bring to light evidence of minor or localized foci of cerebral injury which may later be causes of serious complaints or important in legal and compensation problems In addition, the surgeon should always examine the nose and ears to see if

* This differs from the central type of facial paralysis which follows injury to the facial motor cortex. The paralysis then involves only the lower two thirds of the face; the forehead can be wrinkled and the lids closed and the sense of taste remains intact.

there is leakage of cerebrospinal fluid through a fracture in the frontal, sphenoid or ethmoid sinuses or from a ruptured ear drum with a crack in the petrous bone. In such complications the individual must be protected against meningitis by vigorous use of antibiotic drugs in the hopes that the leak will close spontaneously With otor rhea this is usually the case but with rhi norrhea there is often continued leakage which must be sealed off by craniotomy with direct closure of the dural tear in the floor of the anterior fossa (see below p 170)

After completion of the general and neurological examinations his condition permitting the patient may be sent to x ray for routine lateral stereo anteroposterior posteroanterior and special films of the oc cipital region and base of the skull Since fractures may involve legal complications it is wise to have x rays made even in rela tively mild cases of head trauma.

Certain fractures are of special impor tance As mentioned above cracks running across the temporal region or the longitu dinal or transverse sinuses are likely to result in epidural bleeding Others running into the foramen magnum may be accom-panied by cerebellar contusion with such severe swelling that the cerebellar tonsils are forced down into the foramen magnum We have seen two recent tragic examples of this in healthy young individuals Each at first seemed to have had only minor concus sion, recovered consciousness without seri ous complaints and then died suddenly of respiratory failure from compression of the medulla

It is important to bear in mind that a fracture which is not grossly depressed is not in itself a serious matter What really counts is the damage to the brain its cra nial nerves and blood vessels and the opening up of pathways for infection that may lead to meningitis or brain abscess Fractures across the base of the skull are difficult to see in the x ray and the only clues to their presence may be damage to cranial nerves leakage of cerebrospinal fluid from the nose or ear or the appear ance of an arteriovenous fistula in the cav ernous sinus *

An early lumbar puncture is of value in establishing a base line of the cerebrospinal fluid pressure and for detecting any subse-quent increase from post traumatic cere-bral swelling subdural hemorrhage or the presence of subarachnoid bleeding from cortical laceration Lumbar puncture should never be done in the presence of a possible pressure cone Furthermore it is not always helpful in ruling out epi or sub-dural hemorrhages The lumbar pressure is not necessarily elevated even with serious acute cerebral compression, and red cells from an epi or subdural hemorrhage do not enter the subarachnoid space unless the meninges are torn

TREATMENT OF CEREBRAL INJURIES

After an uncomplicated concussion in which there has been loss of consciousness for but a few minutes no treatment is necessary If however there is residual headache or drowsiness or a fracture the patient should be kept in the hospital. This is particularly advisable when a fracture crosses the groove of the middle meningeal artery or one of its tributaries and in the presence of a crack across any of the venous sinuses in the region of the foramen mag-num or at the base of the skull, even if the individual claims that he feels perfectly well The nurses should be instructed to re-cord the blood pressure pulse and respira tions every hour during the night also to make sure that there is no secondary re-duction in consciousness inequality of the pupils or weakness or convulsive move-ments of the extremities There are many cases on record in which without these precautions the victim of epidural bleed ing has gone to sleep later in the day and then been found unrousable a number of hours later By the time deep coma is reached the brain has all too often been

* This complication is easily diagnosed by an audible bruit synchronous with the heartbeat and the gradual development of a pulsating exoph-thalmos

fatally compressed Such a complication can be avoided if the patient is kept under careful supervision If comfortable and free of headache he need not remain in bed and if all goes well he can be discharged after a day or two When there has been a fracture or the patient complains of headache a lumbar puncture should be done to ascertain whether there is blood in the cerebrospinal fluid from cortical laceration or an elevation of intracranial pressure If this is the case it is best to keep the patient hospitalized until the red cells clear and the pressure returns to normal and then to have him take several weeks off before returning to work

In the case of abnormal neurological signs or failure to recover a normal state of consciousness the first essential is to place the patient under the most favorable conditions for recovery from his cerebral contusion

To insure a clear airway in a deeply comatose individual it is necessary to keep him on his side with a pharyngeal tube to hold the tongue forward and to have a competent nurse in attendance who can suction away pharyngeal secretions Oxygen can be given by nasal catheter BLB mask or a tent if the respirations are shallow or irregular This is of particular importance in young children If the airway continues to be a problem a tracheotomy may be lifesaving since it permits effective suction of deep tracheobronchial secretions in the absence of a cough reflex

The unconscious individual must be turned hourly in bed the restless one controlled by adequate sedation with paraldehyde or barbiturates and protected by strapping the arms to the side of the bed or by a fishnet secured to the top of the bed boards. In the acute phase if the rectal temperature rises above 103 F hyperthermia should be combated by alcohol sponging a cooled oxygen tent and if necessary by ice in plastic bags applied to the skin

To facilitate nursing care and prevent pressure sores it is best to insert an inlying Foley catheter in any incontinent patient and connect it by a Y tube to a reservoir of sterile irrigating fluid as well as to the drainage bottle under the bed For care of prolonged incontinence of urine see page 195 The bowels should be emptied by enema every second day and the rectum examined for fecal impaction every third or fourth day

In order to maintain adequate fluids and electrolyte balance 2 000 cc of dextrose in distilled water with an added 500 cc of dextrose in normal saline solution should be given intravenously for the first few days of coma * This amount will not overhydrate the body and in the absence of a high fever should suffice to insure 1 000 cc of urinary secretion unless the weather is unusually hot or the kidneys are unable to concentrate to a specific gravity of 1 020 or more Feeding by nasal gastric catheter is required to maintain sufficient intake of calories and protein over longer periods When the patient has been treated for a number of days at another hospital and particularly in the case of a child dehydration and changes in electrolyte balance should be guarded against. Toxic dehydration with acidosis has been stressed by Munro but should only occur in badly treated cases On the other hand shifts in sodium either hypo- or hypernatremia, and uremia may develop in any case of severe cerebral contusion According to Lewin s findings nearly a quarter of the severe head injuries (individuals in coma for over 24 hours) develop major metabolic disturbances attended by a high rate of mortality Some of these disturbances are correctable by early treatment and "the evidence suggests that attention to the metabolic requirements of the unconscious patient should form part of

* Formerly active dehydration was advocated to prevent cerebral edema. We have given this up but intravenous fluid may be limited to 1,500 cc. the first day It is not advisable to give only 5 per cent dextrose solution in water because the latter without any added salt causes a distinct rise in cerebrospinal fluid pressure (Bakay Crawford, and White) Use of hypertonic solutions (50 per cent glucose or sucrose) gives only a transitory reduction of cerebral swelling at the price of general dehydration. A single injection of 100 cc. of 50 per cent sucrose is justified only at the time of operation when cerebral herniation cannot be controlled.

the basic management of the acute head injury and that it is a factor in lowering the over all mortality "

Under these conditions the brain swelling will usually subside with gradual recovery of consciousness unless there has been irreversible damage to the midbrain Three years ago a patient at Massachusetts General Hospital remained in coma on this regime for 11 days For the first 3 days he showed the characteristic signs of decerebrate rigidity with periodic extensor spasms. Aspiration of tracheobronchial secretions had been a problem until a tracheotomy was performed. Despite such an apparently hopeless situation, this young man recovered without any residual neurological impairment and returned to his former work on the railroad Many persons however have been less fortunate and have died sooner or later without regaining consciousness At postmortem these patients have usually shown evidence of injury to the brain stem.

Early surgical intervention is necessary only for (1) debridement of open fractures with removal of indriven fragments (2) evacuation of intracranial clots and (3) elevation of depressed fractures These techniques are described below

Debridement of Open Fractures with Removal of Indriven Fragments and Necrotic Brain

Repair of a penetrating wound either from a severe blow on the head or a missile should be carried out as soon as circumstances permit Blood should be replaced if much has been lost from the scalp laceration and other injuries attended to as circumstances demand Sucking wounds of the chest pericardial bleeding or ruptured abdominal viscera should have first priority unless there is threatened compression of the brain from an expanding clot In this event two teams can operate simultaneously Major fractures of the arm or leg should be splinted to prevent further displacement and trauma to the surrounding tissues The fracture can be set later at a more convenient moment. Open fractures of long bones can be dealt with at the same time as the head wound if neither injury is too severe If one is much more serious this one should be operated on first. With antibiotic medication it is safe to postpone debridement of the cranial wound up to 24 hours provided that there is no deep bleeding and that the scalp has been shaved cleansed and covered with a sterile dressing The first operation should be the complete debridement and closure of the wound.

In preparing the patient for operation, morphine should *never* be used It is wise to give 0 6 mg of atropine to reduce tracheopharyngeal secretion. Ordinarily the entire head should be shaved and even for the debridement of a small wound the hair should be removed for 2–3 inches beyond any possible extent of the incision The scalp should then be thoroughly scrubbed with sterile soap solution followed by application of alcohol and dilute (3 per cent) tincture of iodine or some comparable disinfectant. The antiseptic solution should never be applied to any part of the wound.

For anesthesia local infiltration is best in most adults and in all comatose individuals For infiltration of the scalp procaine (1 per cent) or xylocaine (0 5 per cent) should be used with 0 3 cc. of epinephrine (1 1 000) added to 100 cc. of anesthetic solution If the patient is restless and uncontrollable a general anesthetic may be necessary For this intravenous Pentothal* and nitrous oxide with intratracheal intubation are most satisfactory The intubation should be performed with a muscle-relaxant drug if it is feared that life is endangered by a temporal or cerebellar pressure cone In these circumstances coughing or straining might lead to serious further herniation of the brain For babies anesthesia is preferably induced with open-drop ether followed by intratracheal intubation and maintained with semiopen ether oxygen mixtures

In the debridement each layer should be dealt with in turn After thorough cleansing with soap and water plus copious irrigation

with sterile salt solution the scalp edges should be freshened by cutting perpendicular to the skull through all the layers of the scalp Areas of presumably necrotic skin must be excised even if it is necessary to undermine widely or to swing a flap to close the wound subsequently without tension The scalp incision should be enlarged

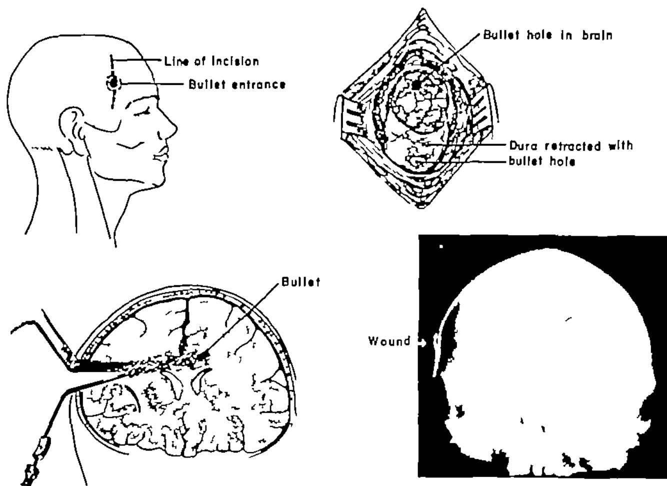


Fig. 115 —Debridement of a gunshot wound Indriven fragments of bone (except the spicule seen over the right orbit in the photograph) and the .22-caliber "short" bullet were removed by suction of necrotic tissue and enlargement of the bullet tract with the aid of a lighted retractor Recovery was uneventful and complete

to give adequate exposure of the fracture taking care that the blood supply from the auriculotemporal supraorbital, or occipital arteries be preserved in the pedicle Small bits of loose bone should be removed and even larger ones if they enter the frontal sinus and are deprived of their blood supply If the remaining bone is grossly contaminated a thin margin of it should be nibbled away at the periphery with a rongeur The entire depth of the wound should be irrigated with copious quantities of warm isotonic salt solution

If the dura has not been penetrated it should not be opened unless it is discolored by underlying blood If it is torn it should be opened widely so that the brain can be examined Pulped necrotic brain is best sucked away it is usually avascular But if any large vessel is torn its ends can be grasped with a fine tissue forceps and electrocoagulated. Normal brain is much more resistant to the sucker If nonviable brain is left behind it forms a ready locus for infection and is likely to swell and produce a pressure cone Later it will form a contracting fibroglial scar which may give rise to epileptic convulsions Therefore every effort should be made to remove the entire area of nonviable tissue suctioning away

injured cortex subpially up to the edge of an intact healthy convolution, as recom mended by Penfield and Jasper

With projectile wounds it is necessary to debride both the wounds of entrance and those of exit. The tract of the missile is best aspirated by suction under direct vision (Fig 115) Necrotic brain sucks away with out resistance exposing indriven bits of bone and superficially lodged bullets or bits of shell fragments These can then be lifted out with a fine pair of forceps without added injury to normal cortex or white matter When a conscious patient is being operated upon under local anesthesia it is a great help to have him hold his breath and strain. The resultant increase in intracranial pressure will help to extrude clots and pulped brain. *Under general anesthesia this can be* accomplished by having the anesthetist compress both jugular veins Deeply situ ated bullets are better left behind if there is danger of injuring important central areas of brain High velocity missiles are usually sterile but if they subsequently form an abscess they can be removed when this is evacuated Occasionally bullets will traverse the brain and lodge beneath the inner table of the skull on the opposite side When this occurs they should be left alone and the patient watched to see if there is subsequent hemorrhage or infection when they can readily be retrieved At the termi nation of the debridement of the projectile wound in the brain the sinus tract should gape and its edges pulsate Unless this much tissue is sucked away residual frag *ments or blood* clots may be left behind as a nidus for infection. If there is a deep cavity or the ventricle is opened this area should be filled with 10–20 cc of a solution of bacitracin (1 000 units per cubic centi meter) and 20 mg of streptomycin For a more complete discussion of projectile wounds the reader should refer to articles by Matson and Meirowsky

After removing all accessible foreign par ticles with surrounding necrotic tissue and securing a completely dry wound the dura should be closed Even if none of the dura has been excised its edges will tend to retract and a tight closure is likely to require grafting with a piece of pericranium or temporal muscle fascia. It is essential that the closure be complete for the dura is an effective barrier against infection or the leakage of cerebrospinal fluid. The remaining larger bony fragments should be drilled at their edges and secured by wire sutures to corresponding drill holes in the rim of the intact skull. When the frontal sinus has been widely opened it is best to remove its mucosa and pass a temporary rubber tissue drain down through the nose

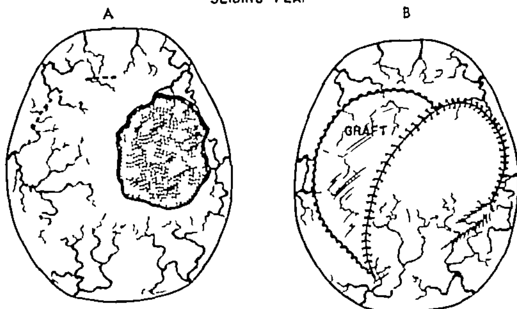
Finally the scalp should be closed in two layers using fine waxed interrupted silk sutures first, for a hemostatic closure of the galea and second to approximate the edges of the skin In suturing wounds that have been grossly contaminated it is preferable *to use a single layer of fine stainless-steel* wire suture and it should be remembered that it is important to include the galea, since this is essential for hemostasis. It is also vital after resection of contused scalp that the suture line be free from ten sion. Whenever the debrided scalp edges cannot be easily approximated it will be necessary to make a relaxing incision or to swing a flap the technique for which is illustrated in Figure 116 The bare area can then be covered by a split thickness skin graft There is no need for a drain. A snug compressive dressing of gauze and elastic bandage is then applied The superficial sutures are removed on the fifth day post operatively Large doses of antibiotics should be given until the wound is firmly healed and there is no underlying fluid If *fluid collects it should be aspirated* and the bloody transudate cultured to make sure it is sterile

Experience in World War II has shown that there is no need to keep a conscious patient in bed If he is allowed up early and given things to do he is much less likely to develop post traumatic headache or psychoneurotic symptoms

Evacuation of Intracranial Clots

The *time to evacuate* either an epi or a subdural clot is before it has produced loss

SLIDING FLAP



RELAXING INCISION

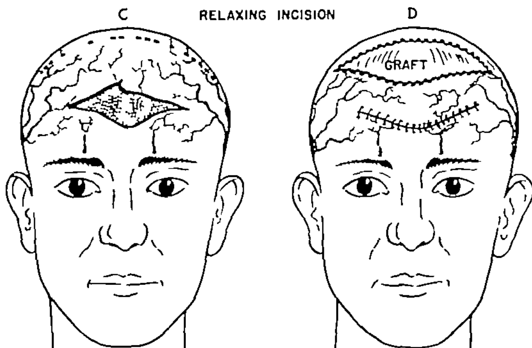


FIG 116 —Repair of extensive scalp wounds to cover compound fractures in the cranial vault or areas of exposed dura mater by sliding flap and relaxing incision Sliding flap A, extent of defect after debridement, with outline of incision designed to preserve an adequate blood supply in the pedicle B the pedicle flap has been freed and shifted to fill in the defect. The denuded area of pericranium from which the flap was taken is then covered with a split thickness skin graft. Relaxing incision C an elliptical loss of scalp tissue can be repaired by making a longer parallel incision leaving a well-vascularized pedicle at each end D the bridging flap has been freed shifted forward and sutured to the anterior edge of the defect, covering the exposed healthy pericranium with a split-thickness skin graft. After suturing the grafts in place with fine silk, a snug dressing should be applied It should be borne in mind that the scalp receives its blood supply from three principal arteries on each side (the supraorbital temporal and occipital branches of the external carotid) There are no sizable perforating branches from the pericranium but a sufficient capillary circulation to nourish a thin split thickness skin graft

of consciousness When there has been no loss of consciousness recovery is usually prompt and complete On the other hand when coma deepens the common cause is compression of the hemisphere to such an extent that the uncus and hippocampal gyrus on the medial inferior surface of the temporal lobe get forced through the notch in the inelastic tentorium. With this im paction the midbrain is squeezed and the aqueduct compressed and there is rapid further increase in pressure from obstruc tion of the outflow of cerebrospinal fluid Consciousness is lost because of compres- sion of the mesencephalic reticular forma tion which Magoun has shown to play such an important role in the maintenance of wakefulness and awareness Evidence warning of this complication is dilation of the pupil from compression of the oculo- motor nerve which runs between the pe- duncle and the cavernous sinus directly in the path of the advancing hernia. This sign does not always occur Both pupils may be dilated or small and unresponsive to light. In severe compression of the midbrain a Babinski sign may appear on the side op- posite the herniation, and occasionally on the injured side when the brain stem is displaced so that the contralateral cerebral peduncle is compressed against the rigid edge of the tentorium on the opposite side. There are large superficial veins at this level of the brain stem which are also com pressed and branches of the basilar artery are stretched so that hemorrhages soon occur in this critical area. At this stage bi lateral extensor rigidity with opisthotonos develops as in the cat after midbrain tran- section Recovery is rare after a severe im paction and there is often too little time to save the patient once consciousness is lost

Extradural Hematoma —Onset of coma soon after a lucid interval is usually due to bleeding from a torn artery on the outer surface of the dura. Usually this bleeding comes from the middle meningeal artery which in adults lies in a deep groove of the temporal squama or greater wing of the sphenoid bone Such bleeding fre quently occurs when a linear or depressed fracture crosses the temporoparietal region. This type of clot is rare in children under 12 because the groove in the inner table of the skull is shallow and the artery is there- fore less likely to be torn Rarely does a hematoma form between the dura and skull without the presence of a visible fracture line Bleeding then occurs from a tiny crack in the inner table of the skull over an epi- dural vessel or venous sinus The complica- tion may also be seen without a preceding lucid interval

A hematoma should be suspected when- ever coma deepens in the first few hours or days but diffuse cerebral edema is also a common contributing factor The only way to diagnose a clot before compression reaches a fatal stage is to make exploratory trephines Schneider and Tytus have ex cellently described the factors that account for such an extremely high mortality in this condition. They emphasize the difficulties in diagnosis and point out that the patient with an expanding epidural hemorrhage may enter a critical stage where respiratory failure is imminent without loss of con- sciousness This is due to compression of accessory respiratory areas in the uncus, anterior temporal region, and the orbital surface of the frontal lobes Patients who have a leakage of cerebrospinal fluid through the ear in addition to a bleeding epidural vessel may develop unusually large clots with minimal danger signs up to the critical point of sudden respiratory and cir culatory collapse

A moribund individual with such a clot may need immediate treatment. In the emergency ward exploratory openings may be made with a ¼ inch metalworker s drill. If blood under pressure is found and re- leased, the time so gained may be lifesav ing In less dire circumstances the patient should be sent to the operating room as soon as this complication is suspected or if warn- ing signs of a dilating pupil or deepening coma are present The operating procedure is as follows

The opening in the skull is made near the fracture line in the temporal region or when

time is too short to take an x ray at a point an inch above and an inch anterior to the superior attachment of the auricle A McKenzie perforator and then a large Hudson burr are used to make a ½ inch opening in this thin portion of the skull The opening can be enlarged by rongeur if bleeding is encountered It is then essential to remove sufficient bone to find the torn vessel and coagulate it Suction is important to keep the area free of blood Oozing from fracture lines must be controlled with bone wax. When the outer surface of the dura or the edge of the longitudinal sinus bleeds profusely Gelfoam® soaked in thrombin or Oxycel® (an absorbable cotton preparation) should be used

When no clot is found at this trephine the dura should be opened and search made for subdural bleeding or discoloration of the brain indicative of a subcortical clot. If nothing is found but the brain is tense it is advisable to make a second opening farther back in the parietal region since occasional clots have been missed from failure to do this If there is a fracture across the torcular Herophili or either transverse sinus or if the lambdoidal suture is separated, it is wise to make an exploratory trephine in the occipital bone with the appearance of any signs of cerebellar compression such as a stiff neck, nystagmus or in-coordination of limb movements

Acute Subdural Hematoma.—Occasionally an acute hemorrhage will be found beneath the dura, which is discolored by blood. Subdural bleeding is usually of venous origin manifesting itself slowly when the extravasated blood has had time to become encapsulated and draw in water with increasing osmotic pressure as its proteins break down to smaller molecules It is possible however for the arachnoid to be torn and for blood from a cortical laceration to get between this inner membrane and the dura. In this way a subdural clot may develop within the first few hours With clots of this type there is often no fracture and no neomembrane will be formed. The hematoma is usually small, but the brain severely contused and swollen

Chronic Subdural Hematoma.—As pointed out above the typical subdural clot produces symptoms after a period of a week or more Its diagnosis may be very difficult. Often the blow on the head has been a mild one The individual if nonobservant or intoxicated at the time of injury may not remember that he ever bumped his head or he may be too confused to answer correctly when questioned regarding this point Symptoms of elevated pressure develop slowly with headache but the spinal fluid pressure on lumbar puncture is not always elevated The spinal fluid is never bloody unless the hematoma is of rapid development the arachnoid is torn or there is added cortical contusion. There is usually a gradual appearance of papilledema The pressure of the expanding clot against the cortex may produce localizing signs such as hemiparesis aphasia or jacksonian seizures progressing to a state of confusion and finally to coma from impaction of the temporal herniation against the midbrain The more obvious signs are often absent, and there is only evidence of increasing pressure This pressure will prove fatal unless prompt measures are taken to find the causative factor and treat it. Roentgenograms may be helpful if the pineal gland is calcified and displaced to one side but frequently the clots are bilateral, and the pineal gland may then remain in its normal position.

Whenever there is a history of a blow on the head and the victim continues to deteriorate instead of getting better bilateral temporal burr holes should be made in the upper temporal region and the dura opened without delay With a less definite history and the possibility that the expanding lesion may be a brain tumor bilateral occipitoparietal openings should be made for ventriculography The clot if present will usually be found this far back when the dura is opened If not fluid should be withdrawn and air injected into the ventricles The site of compression will be localized by distortion of the ventricles in the x ray films regardless of whether the expanding mass be a clot tumor or abscess Only in this way or by arteriography can one make certain of not overlooking atypical or bi

lateral hematomas. Needless to state it is of equal importance to deal with any other types of neoplasms that may have been mistaken for a clot.

In the presence of a typical subdural hematoma it is best to make anterior and posterior burr holes (Fig 117) If the clot is liquid the blood can be removed by suction and irrigation If a solid one a bone flap can be turned down, incorporating the original burr holes and opening the dura widely In this way solid portions of clot as well as a large part of its inner and outer membranes can be removed. The brain should always be retracted and search made for bits of clot at the tip of the frontal pole and under the temporal lobe In children it is important to remove as much of the inner and outer membranes as possible since when left behind these may prevent proper development of the growing cortex. After removing such a clot an exploratory trephine opening should always be made on the other side of the skull because subdural hematomas are often bilateral

If the hematoma is diagnosed and removed early prompt and complete recovery is the rule. With very large hematomas the brain may fail to re-expand and there may be a *complicating midbrain compression.* In these circumstances La Londe and Gardner have advocated attempting to re-expand the collapsed ventricles and brain by injection of saline or Hartmann's solution into the lumbar subarachnoid space Gillingham advocates this same maneuver for reduction of the pressure cone after the clot has been removed. He claims that on rapid and forceful injection of 100 cc. of saline solution by lumbar puncture there is often a lessening of resistance as the impacted portion of the temporal lobe is pushed up out of the tentorial notch and "usually an immediate improvement in the patient's condition." This seems to be a much more logical procedure than attempting to cut the tentorium in an effort to decompress the hernia which involves further surgical trauma of the contused brain. Gillingham's suggestion warrants careful trial because in our experience these patients have done badly Recovery of con-

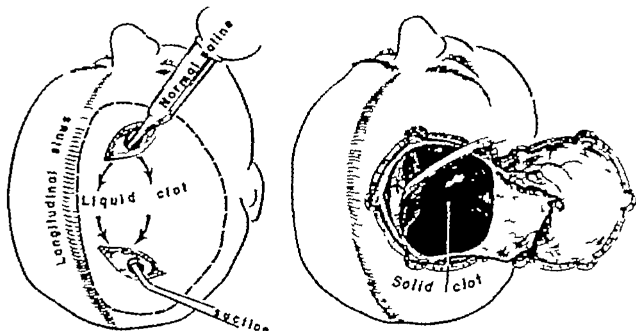


Fig 117 —Removal of subdural hematomas Left aspiration and irrigation of a liquid clot through a pair of trephine openings Right removal of solid clot at craniotomy The dura has been reflected, and the outer and inner membranes are being freed from the arachnoid and cortex. After resection of the exposed central portion much of the frontal and occipital clot can be drawn out piecemeal by sucker and pituitary rongeur

sciousness is slow and death a frequent termination

Elevation of Depressed Fractures

Depressed fractures may result from localized trauma of considerable force such as a blow from a hammer a driven golf ball, or the head striking the edge of a table In more extensive fractures the fragments necessarily require elevation in an adult especially if the depressions are far removed from the motor area On the other hand it is advisable to eliminate any actual indentation of the cortex particularly when this is close to the motor sensory speech or visual areas This is especially important in the developing brain of a child to prevent epileptic seizures

Palpation of the scalp is sometimes misleading because a subgaleal hematoma

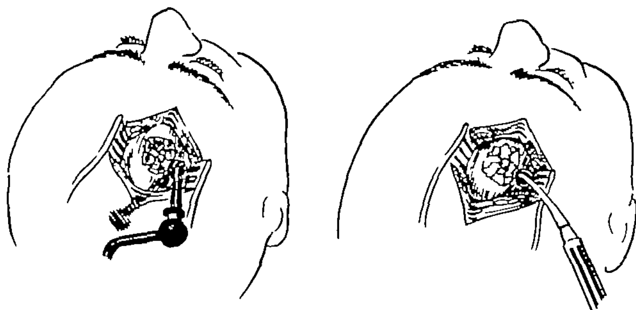


Fig 118 —Elevation of a depressed fracture The buckled in fragments are usually so impacted that it is necessary to make a peripheral burr hole. This permits the surgeon to pry up the fragments, which can be either removed or if large (as in Fig 110 C) drilled and wired in position

may also be driven inward and become impacted In young children the thin skull may be buckled in, so that it resembles the indentation in a ping pong ball that has struck a pointed object.

When a cranial fracture has been driven down beneath the inner table of the skull it is important to restore the table to its normal position whenever there is a possibility of underlying damage to the dura and cortex. This need be done at once only if there is a likelihood of coincident damage to one of the dural arteries or venous sinuses when the fracture is complicated by a laceration of the scalp or if epileptic seizures set in Slight depressions of the inner table when the dura is presumably intact do not may easily obscure the underlying bone depression Also at times a softening in the center of such a clot may be mistaken for a depressed fracture The presence and degree of depression can always be demonstrated by stereoscopic x ray films Often there is a line of increased density where the displaced fragment has slipped beneath the rim of the intact cranium

In elevating a depressed fragment of cranium it is necessary to turn down a flap of scalp large enough to expose the entire area. A burr hole is made in the edge of the intact skull so that the impacted indriven bone can be pried up with a periosteal elevator (Fig 118) When the dura is torn any underlying blood or necrotic cortex

should be sucked away and the dura carefully sutured Small loose bits of bone are best removed. Larger fragments can be secured in proper position by making drill holes at their edges and suturing them with fine stainless-steel wires to corresponding drill holes in the intact cranial rim

If the longitudinal sinus or one of the transverse sinuses is torn there is likely to be diffuse bleeding An ample supply of typed blood should be available and a transfusion should be started before the *surgeon begins to elevate the fracture* Owing to the low venous pressure bleeding —once the tear in the sinus is exposed—can easily be controlled with Gelfoam® or pieces of temporal muscle stitched down to the neighboring dura, as described by Meirowsky It is important not to ligate the longitudinal sinus behind the central rolandic vein for this leads to venous stasis in the upper motor area and is likely to result in spastic paraplegia. A serious complication of exposing rents in venous sinuses must be pointed out—the danger of air embolism These operations should never be done with the patient in the sitting position The table should be nearly horizontal but arranged so that the head can be elevated if bleeding becomes too profuse

COMPLICATIONS IN CEREBRAL INJURIES

The complications that are amenable to surgical correction are continued leakage of cerebrospinal fluid from the nose or ear pulsating exophthalmos from a tear of the internal carotid artery within the cavernous sinus epileptic seizures and persistent facial paralysis Otorrhea through a fracture in the petrous bone and a torn eardrum will usually heal spontaneously Antibiotic medication will generally prevent any early tendency for infection to spread into the meninges unless there is pre-existent infection of the middle ear or paranasal sinuses Cerebrospinal fluid leaking from the nose can be differentiated from catarrhal secretion by its lower protein and higher sugar content. The patient should be instructed to wipe drops away and not to blow his nose lest air be forced back beneath the meninges or directly into adherent brain with the formation of a cerebral aerocele When rhinorrhea persists over several weeks it is best to do a frontal craniotomy and seal off the leak by a dural flap or fascial transplant. This technique is described in detail by Lewin From his experience with great numbers of head injuries seen at the Special Centre for Head Injuries in Oxford, Lewin emphasizes the importance of closing *off these leaks from fractures of the* paranasal sinuses even if no fracture can be seen on the x ray films. Rhinorrhea occurs from dural tears in nearly one third of the fractures in this area and "carries a risk of meningitis supervening at some time in the future of at least 25 per cent." Of his 26 cases in which infection developed 16 died Even when the nasal dripping ceases spontaneously nature s repair is often inadequate and it may start again often with a fulminating meningitis Since craniotomy for repair of these leaks carries very little risk, Lewin recommends that dural repair be considered in all cases of paranasal sinus fracture with rhinorrhea whether this is of early or late onset, of brief or long duration

When there is a basilar fracture across the sphenoid bone in the region of the sella turcica, the internal carotid artery may be torn within the cavernous sinus. This results in an arteriovenous fistula which produces a bruit synchronous with the pulse beat and disturbs the subject by the continued swishing noise in his head. The bruit can easily be heard by auscultation with a stethoscope applied to the scalp in the temporal area. Such an injury leads to a pulsating exophthalmos on the side of the fistula or of both eyes with engorgement of the conjunctival and orbital veins from the increased pressure of arterial blood The bruit and pulsations cease when the carotid artery is compressed in the neck. As Dandy has shown internal carotid ligation will often result in a cure and is usually well tolerated in this condition In a few instances in which there is an excessive collateral circulation from the circle of Willis

on the opposite side it is later necessary for the neurosurgeon to perform a craniotomy and clip the internal carotid as it emerges from the cavernous sinus lateral to the optic nerve When this is done the fistula is trapped between the two ligatures Although this segment includes the origin of the ophthalmic artery the eye will still have an adequate circulation via collateral channels from the external carotid

Seizures which develop in the early period after a head injury can usually be controlled by anticonvulsant drugs They do not necessarily indicate that chronic epilepsy will persist Headache that is troublesome and at times incapacitating is another problem in the convalescent stage Fortunately it does not occur very frequently but it may be a difficult complication to treat even after a relatively minor trauma This is a problem for the neurologist and psychiatrist not for the surgeon concerned with the acute aspects of trauma. The reader who wishes to inform himself on this difficult problem should consult Wolff's monograph on headache

A final problem happily rarely encountered today after adequate surgery and use of antibiotic drugs is late sepsis This may consist of infection and necrosis of the scalp after inadequate debridement or too tight suture osteomyelitis meningitis cerebritis brain abscess and hernia cerebri. There has been no major postoperative infection at the Massachusetts General Hospital in a series of 55 open fractures in civilians Such infection occurs more frequently in wartime injuries and has been well described in Korean casualties by Meirowsky and Harsh and by Matson. These complications are usually the aftermath of inadequate primary debridement or faulty closure of the dura and scalp and must be corrected by a secondary more radical operation Necrotic scalp must be removed and pedicle flaps swung in to close the gap without tension Devitalized infected bone must be removed regardless of the defect involved This can be repaired by subsequent cranioplasty Retained fragments of bone and metallic particles previously located by x ray studies will be found surrounded by pockets of pus or infected clot and can be easily removed

In dealing with infections of the brain the area of cerebritis must be widely excised by suction down to healthy cortex and white matter followed by a secondary tight closure of the dura and scalp Chronic abscesses from a retained foreign body or infected clot can often be removed with their surrounding membrane When there is a large protrusion of infected brain (hernia cerebri) it should be treated by radical removal of thrombosed infected tissue and left open for irrigation through catheters placed in the dressing With frequent lumbar punctures the swelling may recede beneath the skull so that a secondary closure can be done With meningitis it is essential to eliminate the cause by removal of a retained foreign body or by closure of a scalp fistula or leak into the paranasal sinuses

In all these infected cases efficient antibiotic medication will often make the difference between life and death It is vital to know the sensitivity of the organisms present In general, bacitracin is the best medication for local instillation into an infected ventricle or abscess cavity also for injection twice daily by lumbar puncture during the period of meningitis Few gram positive organisms have developed resistance to it and in concentrations of 1 000 units per cubic centimeter up to 25 cc in total volume it is well tolerated by the brain and spinal cord When this antibiotic is not available penicillin in similar dosage combined with streptomycin should be used Streptomycin (25 mg in 25 cc of saline solution) is most effective with the gram negative bacteria and polymyxin (5 mg) in pyocyaneus infection With local, intraventricular or subarachnoid injection and high systemic concentration of the most appropriate antibiotic drugs * it has been possible to save many of the victims of late

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* Polymyxin is too toxic to the kidneys to permit parenteral injection; and bacitracin for similar reasons is best limited to local instillation.

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RESULTS IN TREATMENT OF HEAD INJURIES

In evaluating the outcome of craniocerebral injuries seen at the Massachusetts General Hospital, only the serious cases (226) which required admission to the wards have been included. A larger number with minor fractures and no obvious damage to the brain were treated briefly in the emergency or overnight wards and then sent home It has not been possible to obtain accurate data on this latter group but beyond the occasional complaint of post traumatic headache there were few complications

MORTALITY STATISTICS

The death rate at the Massachusetts General Hospital amounted to 32 per cent in this series of 226 admissions to the neurosurgical service This is higher than the figures from three of the leading clinics in this country and England 17% as recorded by Munro at the Boston City Hospital 23% by Jefferson from two Manchester hospitals and 9% by Lewin from the Special Centre for Head Injuries at Oxford The higher mortality rate at the Massachusetts General Hospital may be accounted for by the fact that the figures include only those patients with such severe injuries that they required admission to the neurosurgical wards Those that did not need special care but were discharged after a brief period of observation in the overnight ward or transferred to the fracture and surgical services for treatment of concomitant injuries are not included Lewin, who has the lowest fatality rate points out that he had the great advantage of having the majority of his patients admitted directly to his service Many of the patients at Massachusetts General Hospital who fared badly had been transferred from other hospitals when their condition was becoming critical. It would seem fair to conclude that 1 out of every 3 or 4 patients with a cerebral injury severe enough to require more than 24 hours of hospitalization is likely to die When lesser degrees of trauma are included the over all mortality rate drops to a point somewhere between 1 10 and 1 5

The Massachusetts General Hospital statistics have been further broken down according to the types of injury in Table 2 Examination of this table will show that, in the absence of cerebral contusion or intracerebral bleeding death should rarely occur When these complications are present the mortality rate is high Of 12 patients with simple fractures and added cerebral contusion 50 per cent died. In 38 others without fracture or gross hemorrhage the mortality rate was 42 per cent. The cause of death was post traumatic swelling of the brain which led to pressure coning and compression of the brain stem An equally high mortality 47 per cent occurred in the epidural hemorrhages In published reports the mortality rate has varied from 55 per cent according to Brock down to 22 per cent, in Lewin s statistics Epidural hemorrhage is particularly dangerous because the progress of symptoms with these arterial clots is so rapid that the majority do not reach the hospital until the patient is in deep coma from compression of the mid brain by herniation of the temporal lobe This was the situation in two thirds of the 15 patients with epidural hemorrhage at Massachusetts General Hospital. To save a higher proportion of these patients physicians in general will have to become more aware of the possibility of this complication and general surgeons will need to learn how to evacuate the clot and deal with the bleeding meningeal artery in their local hospitals Acute intracranial hemorrhage constitutes the single condition where time often does not permit safe transfer to a neurosurgeon

Subdural hemorrhage also accounts for a large proportion of deaths 42 per cent of the 71 cases in the Massachusetts General Hospital series (35 per cent in the series reported by Brock) The frequency of this

TABLE 2.—SUMMARY OF STATISTICS ON INTRACRANIAL INJURY*

Group	Classification	Total Cases	Survived	Died	Mortality	Residual Damage
I	Closed fractures without gross cerebral or vascular injury	7	7	0	0%	1 partial loss of hearing (unilateral)
II	Closed fractures with cerebral contusion	12	6	6	50%	1 slight residual right hemiparesis 1 aphasia, clearing
III	Depressed fracture without gross cerebral damage	6	6	0	0%	0
IV	Depressed fracture with cerebral contusion	4	3	1	25%	1 mild residual hemiparesis
V	Open fracture without gross cerebral damage	19	19	0	0%	0
VI	Open fracture with cerebral contusion	36	28	8	22%	1 homonymous hemi anopsia 1 right hemiplegia 1 peripheral facial palsy 1 oculomotor palsy
VII	Missile wounds	16	11	5	31%	1 quadriparesis 2 bilateral blindness 1 monocular blindness 1 abducens palsy 4 changes in personality 1 focal seizures
VIII	Contusion without fracture or gross hemorrhage	38	22	16	42%	1 hemiparesis (arm) 1 partial amnesia 2 defects in memory 2 changes in personality
IX	Epidural hemorrhage	15	8	7	47%	1 aphasia (recovering) with seizures 1 oculomotor paralysis with mental retardation 1 post traumatic syndrome 1 depression
X	Subdural hemorrhage	71	41	30	42%	4 changes in personality 2 seizures 3 persistent comas (decerebration) 3 oculomotor palsies 1 hemiparesis
XI	Intracerebral hemorrhage	2	2	0	0%	0
	Total	226	153	73	32%	

* A series of 226 severe craniocerebral injuries admitted to the wards at the Massachusetts General Hospital.

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syndrome is of interest since nearly a third of the entire series of 226 patients was found to have significant amounts of blood between the dura and arachnoid Furthermore it is important to subdivide this series of subdural hemorrhages into two groups the acute hemorrhages that occur with serious swelling of the brain within the first 7 days following injury and the classic *chronic subdural hemorrhages that develop* enveloping membranes and begin to expand after a longer period When analyzed in this way the typical chronic dural clot (36 patients) carried a 17 per cent risk of fatality No patient died in whom a clot was not suspected and sought for but in 1 patient in whom no lesion was found post mortem examination revealed that the exploratory opening had been made just below the lower extent of the membranes Acute subdural hemorrhage on the other hand is the most serious form of intracranial lesion 24 out of 35 patients (69 per cent) succumbed The exceedingly high mortality in the acute and subacute forms of subdural bleeding is accounted for by the fact that these relatively small clots were all accompanied by severe contusion of the brain. No membranes were found in this group In the acute subdural hematoma the damage cannot be due to a torn vein within the subdural space venous pressure is too low to produce serious cerebral compression Either the subdural bleeding is merely coincidental (not the major critical factor) or the arachnoid is torn and blood enters this space from a cortical laceration Immediate exploratory trephination and evacuation of the clot or the decompression nevertheless appeared to be a lifesaving *measure* in a few of these moribund patients

With present therapy open wounds of the skull and brain can be closed with only slight risk of septic complications Meningitis osteomyelitis and brain abscess did not develop in any of the 71 patients with open wounds in the series of 226 patients at Massachusetts General Hospital

It may well surprise the general surgeon that mortality rates are distinctly lower in penetrating missile wounds of the brain (31 per cent) and in the open fractures even with evidence of severe cerebral contusion (22 per cent) This is probably because the severely compounded fracture provides an immediate decompression and permits the escape of blood also because at the time of debridement the surgeon *sucked away the pulped necrotic tissue* and thereby reduced the risk of lethal herniation. The source of greatest danger to the victim of a severe head injury is cerebral swelling within the rigid confines of the skull, since this frequently leads to temporal or cerebellar pressure coning with compression of the vital centers of consciousness in the midbrain and of respiration in the medulla.

A final point to be mentioned in connection with prognosis after craniocerebral injuries is that the great majority of patients survive if they do not die in the first few days The first day particularly the first few hours after injury is the most critical period Of 72 fatalities in the series of 226 patients nearly one half of the deaths occurred in the first 24 hours Another third occurred during the next 6 days and the remaining sixth at a declining tempo over the ensuing weeks and months

Lasting Complications of Intracranial Injury

Frequently the early manifestations of neurological injury are reversible and clear up as the contusion subsides Two patients who were in extensor rigidity with decerebrate seizures for several days recovered completely both after periods of unconsciousness lasting nearly 2 months Initial hemiplegia aphasia and defects in the visual fields cleared gradually in all but 7 patients With injuries to cranial nerves, recovery is less likely Nine patients suffered from cranial nerve paralysis at discharge Of the 155 patients who survived 31 had lasting neurological damage (Table 3) when last heard from

Epileptic seizures which occurred in 9 patients in the acute stage of their injury had disappeared in all but 3 patients at the time of discharge from the hospital It is impossible to give the statistical incidence of chronic epilepsy in this series since permanently recurring seizures develop months to years after injury to the brain

TABLE 3 —LASTING NEUROLOGICAL COMPLICATIONS OF INTRACEREBRAL INJURIES*

Permanent coma	3
Hemiplegia or hemiparesis (1 quadriparesis)	6
Aphasia or dysphasia	2
Visual field defects	1
Cranial nerve palsies	9
Mental retardation and other psychological changes	16
Seizures persisting at discharge	4

Observations of penetrating cerebral injuries after World War I showed that 45 per cent of the patients with penetrating wounds of the dura in which the underlying brain was involved eventually developed seizures 23 per cent when the dura remained intact The incidence of seizures during World War II is almost identical Russell and Whitty have also pointed out that seizures are most likely to occur following the formation of cortical scars near the motor area. A thorough description of this problem and the possibilities of surgical cure by resection of the epileptogenic cicatrix, when anticonvulsant medication fails to control the seizures is given by Penfield and Jasper

* In 31 patients (some had more than a single complication)

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syndrome is of interest since nearly a third of the entire series of 226 patients was found to have significant amounts of blood between the dura and arachnoid Further more it is important to subdivide this series of subdural hemorrhages into two groups the acute hemorrhages that occur with seri ous swelling of the brain within the first 7 days following injury and the classic chronic subdural hemorrhages that develop enveloping membranes and begin to ex pand after a longer period When analyzed in this way the typical chronic dural clot (36 patients) carried a 17 per cent risk of fatality No patient died in whom a clot was not suspected and sought for but in 1 patient in whom no lesion was found post mortem examination revealed that the exploratory opening had been made just below the lower extent of the membranes Acute subdural hemorrhage on the other hand is the most serious form of intra cranial lesion 24 out of 35 patients (69 per cent) succumbed. The exceedingly high mortality in the acute and subacute forms of subdural bleeding is accounted for by the fact that these relatively small clots were all accompanied by severe contusion of the brain. No membranes were found in this group In the acute subdural hematoma, the damage cannot be due to a torn vein within the subdural space venous pressure is too low to produce serious cerebral compression Either the subdural bleeding is merely coincidental (not the major critical factor) or the arachnoid is torn and blood enters this space from a cortical laceration Immediate exploratory trephination and evacuation of the clot or the decompression nevertheless appeared to be a lifesaving measure in a few of these moribund pa tients

With present therapy open wounds of the skull and brain can be closed with only slight risk of septic complications Meningi tis osteomyelitis and brain abscess did not develop in any of the 71 patients with open wounds in the series of 226 patients at Massachusetts General Hospital

It may well surprise the general surgeon that mortality rates are distinctly lower in penetrating missile wounds of the brain (31 per cent) and in the open fractures even with evidence of severe cerebral contusion (22 per cent) This is probably because the severely compounded fracture provides an immediate decompression and permits the escape of blood also because at the time of debridement the surgeon sucked away the pulped necrotic tissue and thereby reduced the risk of lethal hernia tion. The source of greatest danger to the victim of a severe head injury is cerebral swelling within the rigid confines of the skull, since this frequently leads to temporal or cerebellar pressure coning with compression of the vital centers of consciousness in the midbrain and of respira tion in the medulla.

A final point to be mentioned in connec tion with prognosis after craniocerebral injuries is that the great majority of patients survive if they do not die in the first few days The first day particularly the first few hours after injury is the most critical period Of 72 fatalities in the series of 226 patients nearly one half of the deaths occurred in the first 24 hours Another third occurred during the next 6 days and the remaining sixth at a declining tempo over the ensuing weeks and months

Lasting Complications of Intracranial Injury

Frequently the early manifestations of neurological injury are reversible and clear up as the contusion subsides Two patients who were in extensor rigidity with decerebrate seizures for several days recovered completely both after periods of unconsciousness lasting nearly 2 months Initial hemiplegia, aphasia and defects in the visual fields cleared gradually in all but 7 patients With injuries to cranial nerves recovery is less likely Nine patients suf fered from cranial nerve paralysis at discharge Of the 155 patients who survived 31 had lasting neurological damage (Table 3) when last heard from

Epileptic seizures which occurred in 9 patients in the acute stage of their injury had disappeared in all but 3 patients at the time of discharge from the hospital It is impossible to give the statistical incidence of chronic epilepsy in this series since permanently recurring seizures develop months to years after injury to the brain

TABLE 3 —LASTING NEUROLOGICAL COMPLICATIONS OF INTRACEREBRAL INJURIES*

Permanent coma	3
Hemiplegia or hemiparesis (1 quadriparesis)	6
Aphasia or dysphasia	2
Visual field defects	1
Cranial nerve palsies	9
Mental retardation and other psychological changes	16
Seizures persisting at discharge	4

Observations of penetrating cerebral injuries after World War I showed that 45 per cent of the patients with penetrating wounds of the dura in which the underlying brain was involved eventually developed seizures 23 per cent when the dura remained intact The incidence of seizures during World War II is almost identical. Russell and Whitty have also pointed out that seizures are most likely to occur following the formation of cortical scars near the motor area. A thorough description of this problem and the possibilities of surgical cure by resection of the epileptogenic cicatrix, when anticonvulsant medication fails to control the seizures is given by Penfield and Jasper

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15 Injuries to Spinal Cord and Cauda Equina

INJURIES TO THE spinal cord present emer gencies as critical as any that result from accidental trauma Most often they are produced by falls diving into shallow water automobile accidents or gunshot and stab wounds The victim usually a healthy young person finds himself unable to move and to feel his legs or all four extremities At times this complication is masked by loss of consciousness caused by cerebral concussion or previous ingestion of alcohol The association of cervical cord injuries with trauma to the head and shoulder has been pointed out by Coleman and Meredith

In this chapter where space is limited discussion must be focused on the needs of the general practitioner or surgeon who is called on to get the patient to a hospital and to care for him during the early acute stage following his injury Just as soon as the most critical factors that accompany frac tured or dislocated vertebrae and contu sions of the spinal cord have been cared for the patient should be transferred to a large center where specialists trained in handling these difficult cases are available Few small hospitals and relatively few of the larger ones have experts trained in dealing with the complications that follow these injuries and the prolonged course of rehabilitation which will enable the victim to survive and to make the most of his residual functions It will be necessary nevertheless to include here a brief description of the special problems associated with spinal injury and the ways of dealing with them in order that the reader may have an over all understanding of the situation confronting these unfor tunate persons This is important because *such knowledge makes it possible to avoid* or minimize many of the most serious com plications which are likely to develop and which may lead to permanent, severe han dicaps and to avoid other setbacks that may add many months to the period of rehabilitation or may result in death

This chapter is concerned only with the aspects of damage to the cord itself and its spinal roots together with the complicating features that follow in the wake of spinal paralysis The associated fractures and ver tebral dislocations are discussed in Chapter 16

PATHOLOGY

Spinal trauma may produce only edema and transitory paralysis (concussion or mild contusion) On the other hand hemorrhage (hematomyelia) is associated with

more or less disruption of the fibers and ultimate necrosis and cavitation More severe compression results in complete anatomical destruction with replacement of nerve fibers by scar tissue or in actual severance of the cord Severed spinal axons undergo complete degeneration Unlike peripheral nerves they have no Schwann sheath and are incapable of regeneration

LEVEL OF INJURY AND RELATED MORTALITY

Either physiological or anatomical transection above the fifth cervical vertebra is invariably fatal, because the phrenic nerve cells which maintain diaphragmatic breathing are situated at the third and fourth spinal segments For this reason patients with cord contusion above the fifth cervical level rarely reach a hospital alive As swelling extends for some distance above and below the point of contusion injury at the level of the fifth cervical vertebra is very likely to result in a fatal anoxia within the first few hours or days In contrast, uncomplicated injuries to the thoracic cord or cauda equina carry no immediate threat to life Formerly these patients died of late sepsis with complicating amyloid disease which followed malnutrition, long continued immobility chronic infection of the urinary tract, and spreading bedsores According to Prather and Mayfield only 1 out of 5 soldiers of World War I with spinal injury lived to reach a military hospital in this country only 1 in 10 survived the first year and it is estimated that less than 1 per cent of these still remain alive. With present-day knowledge the lethal factors of malnutrition and sepsis can usually be controlled. Of the men who incurred spinal injuries in World War II only 3 per cent of those who survived the acute phase of their wounds and reached the paraplegic center at the Cushing Veterans Administration Hospital have succumbed In Munro s civilian statistics the total early and late mortality rate has dropped to 3 per cent At the Massachusetts General Hospital 5 patients in a series of 52 died in the Hospital within a decade These statistics were based on patients who had been admitted to the Neurosurgical Service having survived the immediate effects of a high cervical transection or other injuries to the chest or abdomen. It is not possible to give accurate statistics of the over all mortality rate because so many victims of these injuries die of asphyxia or of their associated injuries before they can be brought to the hospital

Experience has shown that paraplegics can be taught to care for their bodily needs to walk again with crutches and braces, even to drive a car with hand controls and often to become self supporting Maintenance of life is of questionable value only in those individuals whose arm and hand muscles are permanently crippled Unless transection of the cord is seen at operation the permanence of paralysis can never be predicted with certainty even after crush fractures and striking dislocations of the lower cervical vertebrae This point is well illustrated by the case of an 18-year-old boy who while playing football incurred a fracture-dislocation of his fifth cervical vertebra For the first 10 days after injury he had power only in his shoulder abductors elbow flexors and brachioradialis muscles but 2 years later he walked out of the hospital with only a foot-drop brace and with good control of his bladder and rectum. On follow up after 2½ years he continued to have a partial Brown-Séquard paralysis with mild impairment of motor control on his right side and barely noticeable reduction of sensation on the left He has since been going to college and doing well

PHYSIOLOGY

The immediate result of either physiological or anatomical transection of the spinal cord is interruption of conduction in the ascending and descending fiber tracts and temporary abolition of all reflex activity from spinal shock. As a result sensation is abolished in the dermatomes below the segmental level of the spinal injury (Fig. 119) All sensation in the muscles and other deep structures including the viscera is lost as

well Simultaneously muscular movements are lost in conformity with the spinal levels of innervation shown in Table 37 on page 775

Vasomotor activity and sweating are likewise paralyzed by division of the descending sympathetic axons in the cervical and thoracic portions of the spinal cord With interruption of conduction in the descending visceral pathway there is loss of voluntary control of the bladder and rectum together with loss of sexual function in the male All reflex activity is lost in both skeletal (voluntary) and smooth (involuntary) muscles This stage of areflexia is caused by the temporary loss of function in the cord below the level of injury and is known as "spinal shock." If the subject is maintained in a good state of nutrition and free from severe infection reflex activity begins to return after a week or two Without cerebral inhibition the deep-tendon re

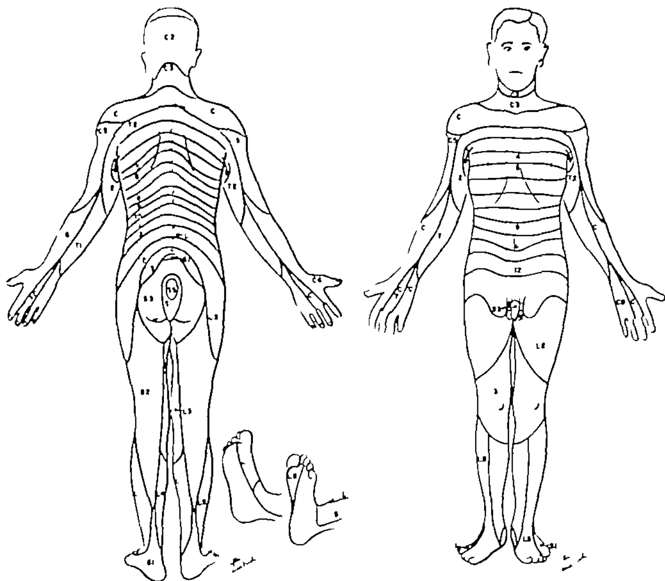


Fig 119 —The dermatomes cutaneous distribution of the posterior root sensory fibers (after Foerster in Haymaker W and Woodhall B : *Peripheral Nerve Injuries Principles of Diagnosis* [2d ed. Philadelphia W B Saunders Company 1953]) The arrows along the vertebral column mark the spinous processes of the first thoracic first lumbar and first sacral vertebrae It is important to bear in mind that the only area in which to test sensation of the first and often the second intercostal nerves is in the axilla and medial surface of the arm In the upper chest and back, these nerves are overlapped by the descending branches of the third and fourth cervical nerves There is no sensory component of the first cervical nerve

flexes then become overactive * As a result spastic paralysis develops with ankle and patellar clonus and an extensor plantar (Babinski) response of the big toe on stroking the sole of the foot The early paralytic ileus and abdominal distention disappear as stretch reflexes recover in the smooth muscle of the intestinal tract Even the ability to empty the bladder and rectum and the erection of the penis on local stimulation, may ultimately return when the reflex arcs mediated through the sacral segments of the cord are restored In cases of high spinal-cord lesions the autonomic reflexes may also become hyperactive When this occurs certain stimuli below the level of the cord injury may lead to areas of excessive sweating and vasoconstriction with bouts of hypertension. On the other hand when the spinal roots of the cauda equina are destroyed by trauma to the lumbosacral vertebrae there will be a flaccid paralysis with poorer recovery of reflex vesicorectal tone and a permanent loss of erection. It is still however possible for the patient to regain a useful degree of control of bladder and bowel emptying mediated by the intrinsic innervation of these hollow viscera (see Table 4 p 201)

CLASSIFICATION

Spinal injuries may be appropriately classified as open or closed depending on whether or not there is a penetrating injury from a stab or projectile wound or on the other hand a fracture dislocation or protrusion of an intervertebral disk or ligamentum flavum from a severe flexion deformity or hyperextension of the vertebral column

Another physiological classification is the division into spastic and flaccid paralysis Spastic paralysis as pointed out above depends on whether the spinal reflex arcs are preserved intact below an injury in the cervical or thoracic region But when the cauda equina is destroyed below the termination of the spinal cord at the level of the first lumbar vertebra or when sepsis and malnutrition have reduced the physiological activity of the cord itself spinal reflexes are lost and paralysis is therefore flaccid in type

DIAGNOSIS

Immediate diagnosis is of utmost importance in order to prevent further damage to the contused cord Time and again a spinal lesion which is incomplete and reversible has been converted into an irreversible transection of the cord or cauda equina by failure to recognize the true nature of the injury

When the victim is fully conscious diagnosis presents no problem since sensory motor paralysis is present and easily recognized below the level of injury A sensory level can be brought out in a complete lesion by testing with a pin or pinching the skin and the injured segment can be localized by comparison with a dermatome chart (Fig 119) Even when the victim is only semiconscious he will usually respond to vigorous pricking or pinching or to firm testicular compression provided the pain pathway in the spinal cord is intact. In a subject who can co-operate the muscles can be tested and the level of injury accurately localized by comparison with the motor paralysis using Table 4 on page 201 Even in the unconscious subject injury at the sacral level can usually be detected by the absence of the ankle jerk and anal sphincter tone A lower thoracic injury can be diagnosed by the added loss of knee jerk† and the absence of sweating in the lower half of the body provided that there is reflex activity and definite moisture in the skin of the arms and upper thorax The victim of cervical paralysis will have total areflexia absence of sweating, with the

* In contrast to the deep-tendon reflexes which become hyperactive when cerebral control is permanently lost, the superficial reflexes (abdominal and cremasteric jerks) never recover after complete destruction of the cord or cauda equina

† Loss of reflexes after severe injuries to the spinal cord proper is noted only during the early period of spinal shock. Later there is hyper reflexia. In contrast when the paralysis results from injury to the cauda equina the leg reflexes will be permanently abolished.

drooping of the eyelids and small pupils seen in the typical Horner s syndrome Priapism (continuous penile erection) is often a striking sign of severe injury to the cervical cord Also blood pressure is low as in a high spinal anesthesia The situation seen in spinal shock after a cervical or high thoracic injury to the cord is however quite different from that in ordinary hemorrhagic shock the patient remains alert (barring cerebral anoxia) does not complain of thirst and maintains an adequate peripheral circulation with a warm dry skin True shock is not seen in transection of the spinal cord unless there is associated loss of blood or other serious injury

When the paralysis is only partial some degree of motor and reflex activity is likely to be preserved but there is often a Babinski extensor plantar response In these injuries the posterior columns are often less seriously injured than the anterolateral spinothalamic tracts As a result some awareness of compression or movements in the extremities is likely to be preserved

When a physician is called to the scene of any accident where the victim has fallen or has been thrown from a moving vehicle he should always think of the possibility of injury to the spinal cord particularly when examination is difficult because of alcoholic intoxication or when there are other injuries to the neck or back.

FIRST AID

Once the diagnosis of injury to the spinal cord has been made the all important principle in first aid is to get the victim to a hospital where he can have adequate care without further injury to his damaged cord or cauda equina. In the panic that follows one of these accidents well meaning bystanders firemen police or even inexperienced physicians are likely to produce irreparable further damage by flexing the neck or attempting to sit the victim up in order to give him a cigarette or a drink or to make him "more comfortable" The usual attempts to get the patient into a car or an ambulance on a sagging stretcher or blanket picking him up by the shoulders and knees or even forcing him to attempt to walk with support are all too likely to lead to a complete transection The "Do s and don t s" of transport are illustrated in Figures 120 and 121

The most important principle is to keep the injured vertebrae immobile and in a physiological position This entails maintenance of normal lordosis in the cervical or lumbar spine Flexion of the neck or lower back is particularly dangerous since either crushing of a vertebral body (Figs 120 *B* and 121 *A*) or dislocation is most likely to have occurred in acute flexion At times however injury to the laminae or articular facets or protrusion of the ligamenta flava in the cervical region has resulted from hyperextension Therefore the wisest course is to hold the injured vertebrae in a neutral position with a mild degree of cervical or lumbar lordosis In the case of a lumbar injury this can best be achieved by putting a pillow or folded blanket under the lower back to support the lumbar vertebrae after smoothing out the ground and emptying the trouser pockets of all hard objects (Fig 121 *C*) A person who is tetraplegic because of a lesion to the cervical cord should be kept on his back with a rolled-up bath towel, blanket or sweater under his neck (Figs 120 *D* and *E*) It is also necessary to avoid lateral movement of the head This can be done by wrapping a bath towel around the neck to form a support between the chin and chest or by improvising a Thomas collar out of folded newspapers or padded cardboard (Fig 120 *C*) If the patient is unconscious or intoxicated and likely to vomit he may have to be rolled over into a prone position (Fig 121 *D*) to prevent inhalation of fluid

There is no need for extreme haste in transporting the patient to the hospital provided that he is protected against loss of body heat by coats or blankets The physician should await the arrival of a suitable flat, rigid stretcher and an ambulance if these can be obtained If not a door or 6-foot wooden shutter padded by a mattress

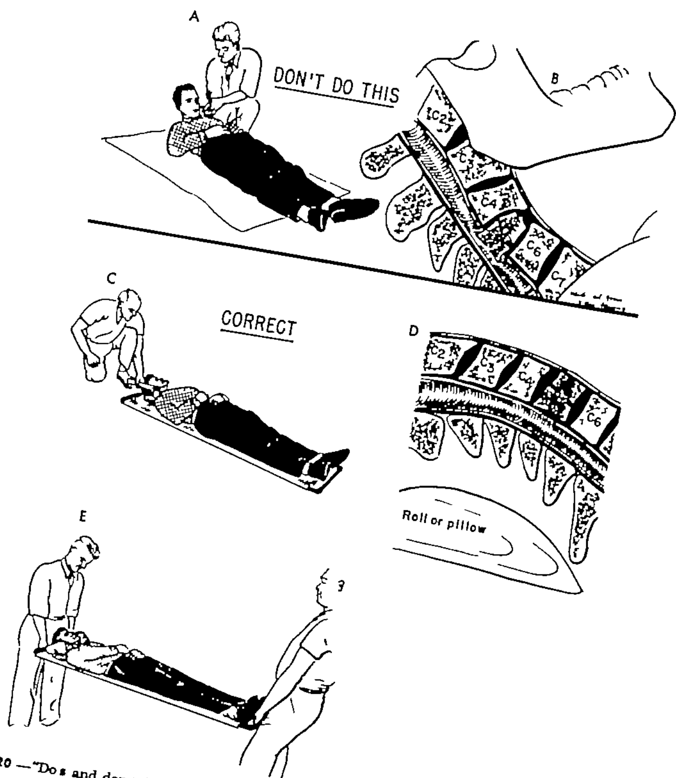
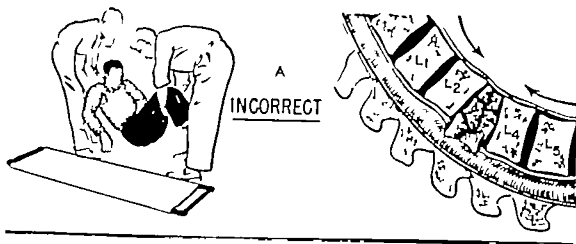
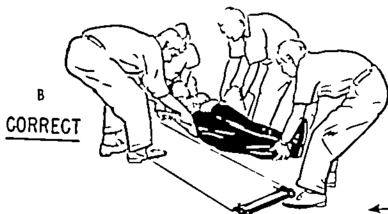
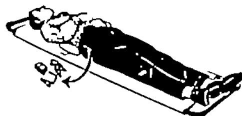


Fig 120 —"Do s and don t s" in transport of patients with injuries of the cervical vertebrae

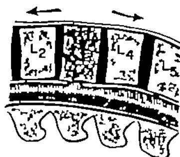




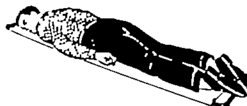
CONSCIOUS PATIENT



C



UNCONSCIOUS PATIENT



D

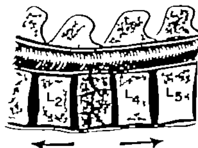


Fig 121 —"Do s and don t s" in transport of patients with injuries of the lumbar and lower thoracic vertebrae

or a number of blankets or quilts will serve the purpose equally well, and transportation can be arranged in a truck or station wagon.* If the accident occurs near a well equipped hospital it may be possible to obtain a turnbuckle collar or a head halter for stabilizing the neck in transport If not traction can be carried out by means of two face towels secured in position by safety pins as shown in Figure 120 C

When all is ready the patient should be lifted onto a flat stretcher Two assistants should support his head and legs while two should maintain lordosis by means of a taut drawsheet or bath towel passed beneath the lower back, as illustrated in Figure 121 B All bony prominences should be padded. In the case of injury to the lumbar spine all that is necessary is a well padded support for the broken back to preserve a slight degree of lordosis in the cervical injury a folded bath towel or sweater under the back of the neck is sufficient. The physician stays by the head at all times and maintains gentle traction on the long axis of the body by means of halter traction (Fig 120 C) Morphine should never be given to any patient with high spinal injury because of the danger of respiratory depression in the presence of reduced respiratory exchange Likewise it is advisable not to use hot water bottles since these may cause burns in anesthetic skin.

HOSPITAL TREATMENT

Treatment of spinal injuries falls into three phases (1) The early stage is the most critical phase because of respiratory difficulty in cervical injuries Regardless of the level of cord injury there will be more or less intestinal distention and spinal shock. This acute stage usually lasts from 10 days to a month (2) The second stage is the period required for healing of the fracture and adjustment to altered neuromuscular visceral, and hormonal physiology The medical team must be constantly on the alert to prevent and to treat the complicating factors of malnutrition, metabolic disturbances urinary sepsis and bedsores This stage usually lasts 3–6 months (3) The final period of rehabilitation is likely to last from 1 to 2 years in a case of complete transection or severe contusion of the cord or cauda equina. During this period the patient must learn to accept the consequences of his injury and be helped to acquire the will to live and rise above his handicaps.

If the patient cannot be transferred to a paraplegic center within the first few days, consultants must be brought in to help in carrying out necessary neurosurgical, orthopædic and urological procedures Final rehabilitation requires continuous skillful physiotherapy to promote maximal development of intact muscles and recovery of the patient s ability to care for himself and to ambulate if he has preserved useful muscles in his shoulders and arms This and the ability to learn a new occupation permitting self-support can best be carried out in a special center

THE ACUTE PHASE OF SPINAL INJURY

General Surgical Medical and Nursing Care

The hospital should be notified that a spinal injury is to be admitted On the arrival of the patient the neurosurgeon who is to be in charge of early treatment should first make a complete physical examination If the patient is in shock† from

* The army in Korea satisfactorily solved the problem of long-distance transport by using two well-padded litters strapped to the front and back of the patient (described by Campbell and Melrowsky) Holes cut in front permit exposure of the face and the passage of an inlying catheter The patient can then be turned as desired in transport by ambulance or plane.

† It is important to point out the difference between true surgical and spinal shock. Surgical shock is rare but a low blood pressure is the rule in the first few days after a cervical or high thoracic contusion of the spinal cord. Much or all of the thoracolumbar sympathetic outflow has been paralyzed, and the patient will have an expanded vascular bed because of widespread vasodilatation. In contrast to a person in shock from loss of blood the tetraplegic has a warm, dry skin, a relatively slow pulse and good color The foot of the bed should be elevated, but transfusion is not ordinarily necessary Within a few days as the spinal autonomic reflexes recover the blood pressure will return to a low normal level.

ss of blood injuries to viscera or other actures he should be given blood trans sion without delay A fractured long bone ay be splinted but aside from a rapidly tal condition such as a tension pneumo-orax the spinal injury should be given st priority

The patient is next taken on his stretcher

In tetraplegia from a cervical injury the patient is next taken to the operating room Oxygen should be administered by nasal catheter or BLB mask if there is limited respiratory exchange The stretcher is placed on the operating table and a neck extension collar is fitted to prevent any movement of the cervical vertebrae Head

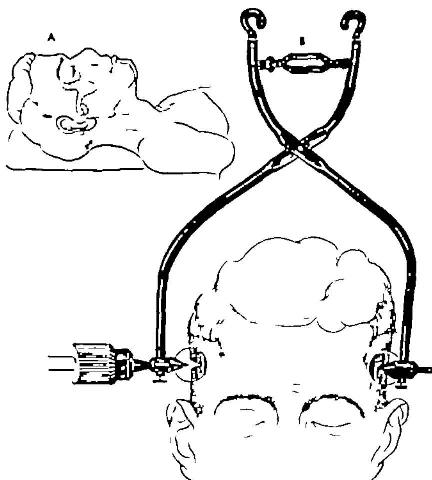


Fig 122.—Cervical traction with Barton tongs A, location of incisions in scalp B tech nique of application of the tongs On left side (of illustration) a twist drill protruding 4 mm s used to make a hole in the outer table of the temporal bone On right side this has been replaced by a metal pin secured in place by the thumbscrew

o the x ray department for anteroposterior and lateral films in order to determine the exact site and extent of the bony injury This can be done without risk of disturbing the fracture or dislocation if the lateral films are taken with the tube in the hori zontal position It is important to point out that there may be a severe contusion of the cervical cord without any radiological evi dence of bony deformity but thoracolumbar injuries will usually show a clear-cut vertebral fracture or dislocation

traction tongs are then applied to the skull The Crutchfield Barton or Blackman tongs all serve this purpose well, but we have found the Barton m ification to he the simpl d most actory (F 122) After are scalp the ears the d of the rt r the the

tightly and fixed by means of set nuts to prevent their subsequent spreading Only tiny dressings of sterile cotton fixed in position by collodion or adhesive elastic bandage are needed to cover the incisions at the points of the tongs So long as trac

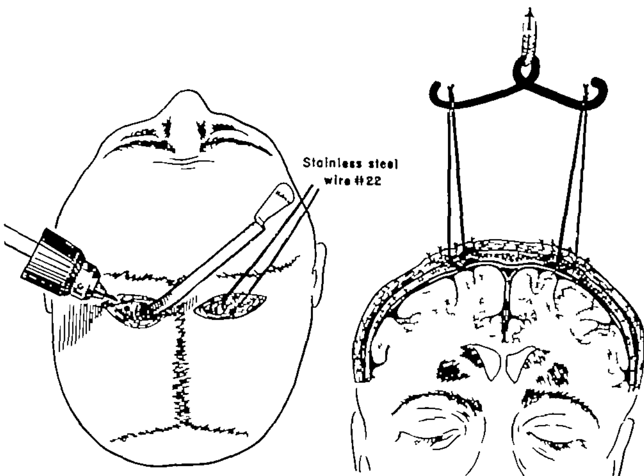


Fig 123 —Cervical traction by means of cranial wires **Left** a 1 cm. opening has been made in the bone down to the dura with a perforator burr A metal guide is slipped into this and a second oblique hole is made with a twist drill. A stainless-steel traction wire has been passed through the two holes between bone and dura. **Right** the traction wires are attached to a metal yoke and the incision closed with a single layer of interrupted fine-silk sutures through the galea and skin

tion is continued all varieties of tongs require periodic tightening or the points may slip out of the skull.

If no proper tongs are available the surgeon can make a 1 cm trephine opening 3 cm on either side of the midline These openings are made through linear incisions in the scalp with the Hudson or Mc Kenzie burrs with a small twist drill hole 1 cm to the side The dura is freed up between the two openings on each side (Fig 123 *left*) Heavy stainless-steel wire is then passed superficial to the dura between each pair and the wire on each side is attached to a metal spreader (Fig. 123 *right*) This method is just as effective as the special tongs for prolonged traction. The wires can be cut and withdrawn at any time We have seen no case of troublesome infection even though traction has been maintained for several months.

The patient still on his original stretcher is then transferred to his bed in the ward The collar is removed and the traction attachment is connected by a rope lead over a pulley at the head of the bed to a suspended weight. Ten to 15 pounds pull is sufficient to maintain vertebral alignment prevent

further injury to the spinal cord and permit safe turning of the patient from side to side This setup is illustrated in Figure 124

The patient with intercostal paralysis and only diaphragmatic respiration requires oxygen during the period of acute injury since hemorrhage and edema may further embarrass the activity of the anterior horn cells of the phrenic nerve at the third and fourth cervical segments The gas may be administered by nasal tube BLB mask, or an oxygen tent. Despite every possible safeguard patients may become stuporous and die of progressive cerebral anoxia. Munro has shown that diaphragmatic respiration may be aided by a snugly fitting swathe or adhesive strapping around the thorax, which prevents expansion of the paralytic rib cage in the expiratory phase and thereby reduces the work of the diaphragm at the beginning of each inspiration. We have found that such strapping may increase the vital capacity by 100 or 200 cc. when it is reduced to a critically low level of 500 cc In addition it is of vital importance to maintain a free airway at all times and to guard against respiratory infection This will require the use of pharyngeal suction and prophylactic administration of penicillin and streptomycin during the early critical stage of spinal shock At times when there is excessive secretion and respiratory exchange becomes critically low tracheotomy is a life saving procedure

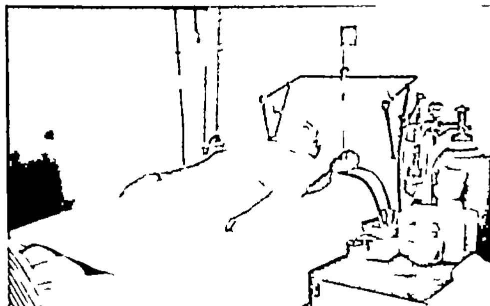


Fig 124 —Treatment of patient with cervical fracture-dislocation and quadriplegia below fifth cervical level Cervical traction by head tongs Rope to weights at head of bed is led over pulley that can slide laterally on adjustable bar Oxygen apparatus with BLB mask. Snug swathe around lower thorax to facilitate more effective diaphragmatic respiration Tidal drainage apparatus to fill and empty bladder periodically (Traction apparatus designed by Dr W A Rogers)

In treating injuries to the lower thoracic or lumbar spine traction is useless The problem here is to maintain vertebral alignment in a position of moderate lordosis since any degree of flexion tends to produce pressure on the vertebral bodies and thus to extrude loose bone fragments or disk cartilage into the spinal canal. Extension can be maintained either by placing a blanket roll 4 inches in diameter under the mattress or by making a carefully padded posterior shell for the patient to lie on when he is in the supine position This shell should extend from the shoulders to the lower portion of the thighs When the patient is turned prone the shell is removed since normal lordosis is then maintained by gravity Although the use of a shell has been condemned by Munro we believe that a

properly constructed one is of great help in maintaining fixation of the fractured vertebrae in turning the patient from front to back, in changing sheets and in the use of the bedpan. We have found no increase in the incidence of bedsores but the padding of the shell over bony prominences and around the aperture under the buttocks is important Pressure on the heels must always be prevented by placing a pillow under the calves from the ankles to the knees and the feet must be held in dorsiflexion of 90 degrees by another pillow placed against the soles When the patient is in the face-down position, the pillow is shifted to support the shins and maintain flexion of the ankles The weight of the bedclothes should be supported by a board at the foot of the bed

Aside from the special features related to the site of injury as described above the general medical and nursing care of spinal injuries is much the same regardless of the level of the lesion.

The general principles are listed below

1 The bladder should be drained. A No 16 Foley catheter should be inserted as soon as the patient is placed in bed. A larger catheter than this should not be used since it is likely to block the orifices of the urethral glands and vasa deferentia thereby leading to urethritis and epididymitis The catheter should be connected to a two-way closed system of sterile tubing to permit bladder drainage into a bottle on the floor beneath and periodic filling to 400 cc with fluid from a reservoir at the head of the bed (Fig. 125 *left*) Further details on bladder care and training are enumerated on page 195

2. During the stage of spinal shock, when there is areflexia of smooth as well as skeletal muscle the patient is prone to develop ileus and intestinal distention. In injuries with respiratory embarrassment this may be a lethal factor Formation of intestinal gases can be reduced by giving no food by mouth and by a high concentration of oxygen in the inspired air The chief intestinal gas is nitrogen. This will be eliminated by physical absorption provided that the nitrogen saturation of the blood leaving the lungs is kept at a low level In cases where distention develops despite these measures Wangensteen suction and a rectal tube should be used. Mouth feeding can be started as soon as audible peristalsis returns

3 Patients with spinal injuries require large volumes of fluid to dilute the urine and hold in solution the high content of calcium which is always lost from bone in cases of paralysis According to Freeman, 500 mg or more is excreted in the urine daily A total 24-hour fluid intake of at least 4 000 cc and a urinary output of 2 000 cc * are important.

4 Catabolism of protein is also greatly increased from the paralyzed muscles and in the "alarm" reaction that accompanies any severe injury with suppression of adrenal corticosteroids It is vital to maintain caloric and nitrogen balance otherwise malnutrition, hypoproteinemia and reversal of the albumin-globulin ratio result in further osteoporosis a reduced resistance to infection poor healing of injured tissues and the formation of pressure sores

Patients with spinal injuries require a daily intake of 3 000 calories and 100–150 Gm. of protein During the acute phase of spinal shock and the attendant paralytic ileus which invariably occurs they will not tolerate oral feedings and must be fed by the parenteral route If this phase of paralytic ileus lasts no more than a week, it is not imperative to attempt a vigorous program directed toward maintenance of a large caloric and protein intake by venoclysis Rather attention should be directed toward maintaining the normal fluid and electrolyte balance which is altered by any severe stress accompanied by adrenocortical activity It must be remembered that some 3 000 cc. of fluid is required daily to assure a urinary output of 1 000 cc. or more If this amount is given intravenously

* With the patient on an adequate diet, its water content and water of oxidation will contribute approximately a liter to the daily volume of fluid

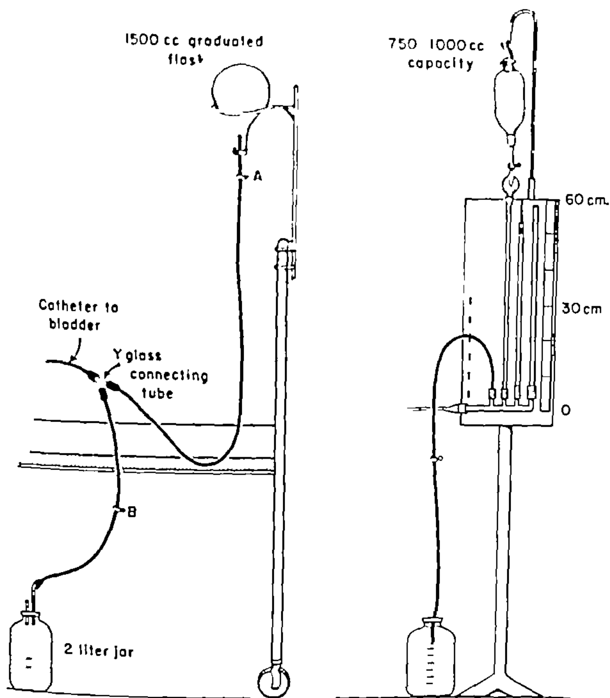


Fig. 125 —Apparatus for bladder drainage Left closed type The urine is allowed to drain into a bottle under the bed It can be filled and irrigated periodically with a sterile solution from reservoir by closing screw clamp *B* on outlet tube and releasing clamp *A* on tubing from reservoir Right tidal drainage and cystometer of Stewart.

in the form of 5 per cent glucose it will provide 600 calories 10 per cent glucose may thrombose precious veins This amount of carbohydrate although it contains far less than the desired number of calories should suffice to burn body fats without the production of ketosis Although there is a tendency for the body to retain salt after stress it is advisable to add 5 Gm of sodium chloride and 3 Gm of potassium chloride to the glucose solution to maintain electrolyte balance *

If the phase of paralytic ileus lasts more than a week, it is advisable to begin a program of parenteral therapy designed to maintain a high caloric and protein intake It is impossible to maintain a high caloric intake by the use of glucose alone and therefore intravenous fat emulsions should be utilized for this purpose The fat emulsions contain about 1 5 calories per cubic centimeter and 1 liter a day can be safely given intravenously Additional calories can be given as glucose and alcohol, and infusions of amino acids in the presence of an adequate caloric intake will help to correct the negative nitrogen balance which is always present.

As soon as intestinal activity has returned, the patient must be encouraged to take the large amount of food necessary to maintain caloric and nitrogen balance by mouth Supplementary between meal feedings of anything that he likes should be encouraged and a high content of vitamins added. Brewer s yeast (ten to twenty 0 5 Gm. tablets) and vitamin C (100 mg a day) will fill these requirements When ever the patient cannot take adequate amounts it may be necessary to resort to nasal gastric tube feedings An excellent account of the nutritional requirements and specific instructions for securing an adequate intake are given in *Injuries of the Spinal Cord* edited by Prather and Mayfield Serum-protein determinations and albumin globulin ratios should be obtained at frequent intervals to prevent development of a protein deficiency Cooper and his associates at the Mayo Clinic claim that daily administration of testosterone propionate (50–100 mg a day) will act as an anticatabolic nitrogen-sparing agent during this period of excessive tissue destruction

5 At this stage anemia is also a frequent complication. Hemoglobin determinations should be made at biweekly intervals and transfusions of whole blood should be given if the level falls below 14 Gm.

6 In order to prevent the formation of pressure sores and decubiti patients require being turned from a supine to a prone position every hour day and night. Such turning is carried out by rolling up the edges of the under sheet on each side and then with two attendants on each side of the mattress rolling the patient over "in one piece" (i.e without torsion) from back to front, or vice versa With the cervical fracture in head traction, this maneuver is readily accomplished but it should be restricted to the lateral and supine positions Turning of the patient with a lumbar fracture is greatly facilitated by the use of a posterior shell, into which he can be strapped It is very important that the nursing staff be taught to turn paralyzed patients smoothly and regularly every hour around the clock. When the patient is in the prone or lateral position his back should be rubbed with alcohol to sterilize the skin, and he should be massaged over the bony prominences to increase circulation. Excessive dryness of the skin can be corrected with lanolin. The sheet under the patient must be kept free of wrinkles bread crumbs and moisture at all times A bed sore may develop in a short time if the patient is left lying on a wet or wrinkled surface

7 Evacuation of the bowels will require enemas These should be started as soon as active peristalsis returns and permits oral feeding They should consist of warm soapy water and should be given at a regular hour on every second day Twice weekly on

* It should be realized that this is only a rough approximation. In the early poststress phase the body requires a little more potassium and less sodium; but for this brief period these amounts should suffice and be quite safe even if there is some renal damage

completing the enema the attendant should make a digital examination in order to remove hard fecal pellets from the rectum and to avoid impaction

8 Early prophylactic administration of penicillin and streptomycin has been recommended above *This medication should* be maintained in adequate dosage particularly in cervical injuries and in elderly patients as long as there is any danger of atelectasis hypostatic pneumonia or other active infection Once the prophylactic drug has been discontinued Gantrisin* should be given in oral doses of 0 5 Gm each 6 or 8 hours over the entire period of catheterization.

9 Phlebothrombosis and pulmonary embolism are likely to develop in patients confined to bed with paralyzed leg muscles Such patients will have no warning muscular tenderness and must be watched for swelling of the calves If this condition develops ligation of the femoral veins should be performed in order to reduce the risk of a clot s becoming detached and leading to fatal embolism of the pulmonary artery

Neurosurgical Procedures to Promote Recovery

Need for operative intervention is obvious in cases of compound fractures of the vertebrae in irreducible dislocations and when the cord is compressed by detached fragments of bone or protruded cartilage from an *intervertebral disk The need for* surgical decompression is clearly shown by x ray when there is a persistent major dislocation of vertebrae protrusion of bone into the spinal canal from a comminuted fracture or a metallic foreign body (Fig 126) Small spicules of bone from fractured laminae or gunshot wounds and disk cartilages which injure the cord will often not be visualized as reported by Cramer and McGowan. *Serious* compression from an intervertebral disk, or in a questionable deformity as seen in the x ray film can usually be diagnosed by spinal manometry carried out by making a lumbar puncture and observing an absent or reduced rise and fall of cerebrospinal fluid in the attached manometer on jugular compression and release (Queckenstedt test) *

In fracture-dislocations of the cervical vertebrae it is usually possible to correct the deformity by forcible traction (Fig 126 *top*) *Weights can be added gradually to a* total of 30 or even 40 pounds if the head of the bed is elevated for countertraction and frequent lateral x rays are taken to make sure there is not excessive separation When done with care this procedure is safe and will usually correct the deformity unless there has been a disarticulation of the cervical facets When cervical traction fails or in dislocation of the thoracic or lumbar vertebrae open decompression and direct manipulation to correct the deformity will be necessary as soon as the patient s condition permits

In judging the best time for surgical intervention all depends on the condition of the patient In the case of lower spinal injuries without respiratory impairment, the necessary procedure can often be undertaken as soon as spinal block has been demonstrated On the other hand when there has been a severe injury to the cord in the neck or upper thorax the risk of surgery in the presence of a low blood pressure and reduced respiratory exchange is much greater than the risk involved in the delay of a day or two Even the definitive debridement of a compound wound can be postponed for 24 or 48 hours if the wound *is cleansed* superficially and protected by a sterile dressing and large doses of antibiotics

When the operation is undertaken for a cervical injury the patient s head is stabilized by a 30-pound pull on the skull tongs which is maintained by traction to an extension rod attached to the head of the operating table With the patient in the

* In order to make a diagnosis of partial block jugular *compression should be performed not man*ually but in a quantitative manner by graded compression with a sphygmomanometer cuff wrapped about the neck. The cuff is inflated for periods of 10 seconds to pressures of 10 20 30 and 40 mm of mercury as the speed and extent of rise and fall in the spinal fluid manometer are recorded.



Fig 126 —X rays of injuries to vertebral column that cause contusion of spinal cord or cauda equina **Top left** fracture-dislocation with forward slipping of fifth cervical vertebra and dislocation of articular facets **Top right** film 24 hours later showing complete reduction after use of 35 pounds traction. **Center left** lateral view of fracture-dislocation with forward slipping of twelfth thoracic vertebra and wedge-shaped crush of first lumbar vertebra. **Center right** film made 2 months later after open reduction and spinal fusion On day of accident the spinous processes of the eleventh and twelfth thoracic and the first lumbar vertebrae with lat

prone position his weight must be supported by his chest pubis and legs the abdomen must be completely free in order not to jeopardize diaphragmatic breathing Incision and exposure of the laminae are carried out under local anesthesia while the anesthetist insures a free airway and a maximal supply of oxygen General anesthesia with Pentothal and nitrous oxide can be used safely only by an anesthetist expert in passing a nasal tracheal tube without extending the cervical spine

Exploration in the lower thoracic lumbar or sacral vertebrae can be undertaken with relative safety on the day of injury if necessary for decompression of the cord or cauda equina correction of severe dislocations or debridement of open injuries These are combined neurosurgical-orthopaedic procedures and the underlying operative steps are the same for any part of the spinal column (Details will be found in Chapter 16) In brief in the case of an open wound the tissues are debrided with removal of severely contused necrotic skin muscle and loose fragments of bone Extreme care must be exercised in the manipulation of fractured laminae lest there be further contusion of the underlying cord. If there has been dislocation of the articular facets the dislocation can often be reduced by increasing traction on the skull or lower extremities under direct vision and prying the facets back into line with the aid of narrow periosteal elevators In compression of the cord by a crushed vertebral body or a disrupted disk cartilage the proper laminae must be resected to allow adequate decompression and exploration of the spinal canal The dura is opened to estimate the degree of cord contusion or transection and to make sure that there are no indriven spicules of bone in a penetrating missile wound When the projectile tract has passed through a hollow viscus it is important to repair any rent in the dura which might give access to infection and meningitis

When this portion of the operation has been completed it is advisable whenever possible to stabilize the injured vertebrae This can often be done by removing articular cartilage wiring adjacent spinous processes if they are intact and adding chips of bone if these can be obtained from a local source or the bone bank The work of *Cone and Turner has shown the great ad*vantage of early fusion which permits a wider range of movement and more active physiotherapy thereby reducing the tendency to skeletal decalcification * urinary stone formation and the development of pressure sores A description of these orthopaedic procedures is given in Chapter 16

STAGE OF ADJUSTMENT TO SPINAL INJURY

Once the critical problems of inadequate respiratory exchange spinal shock with its accompanying paralytic ileus and the acute surgical emergencies discussed above have been dealt with a host of new problems arise and many of the original ones still persist. The new ones are associated with altered metabolism, mental depression, and the physiological disturbances that follow paralysis of the extremities bladder and lower bowel Their treatment requires the constant attention of most of the services in a large general hospital—the internist and dietitian neurosurgeon urologist orthopaedist, physiotherapist

* The observations of Albright and his co-workers have stressed the fact that it is the absence of the usual stresses and strains of activity and weight bearing which decreases osteoblastic action and Freeman has pointed out the striking reduction in urinary calcium excretion which takes place as soon as active motion is started

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eral grafts of bank bone were wired together **Bottom** lateral and anteroposterior views showing bullet (45 cal.) that penetrated first lumbar intervertebral foramen. Although the dura was penetrated and the conus medullaris with its emerging caudal roots was contused this United States marine was able to return to duty 3 months after removal of the bullet and repair of the dural tear

plastic surgeon psychiatrist chaplain, and social worker Their roles are discussed under the following headings

Nutrition and General Medical Care

The metabolic needs of the paralytic patient have already been outlined To insure an intake of 3 000 calories and 100+ Gm of protein is not an easy matter To correct the nutritional deficiencies and hypoproteinemia it may still be necessary to resort to feeding by nasal gastric tube When the patient can take an adequate amount by mouth supplementary feeding between meals may still be necessary This requires catering to the patient s tastes and keeping an accurate record of the amount of food ingested, together with the 24-hour intake and output of fluid Milk must be avoided as much as possible because of its high calcium content and the tendency to urinary stone formation The hemoglobin and serum protein levels should be followed until normal values have been maintained for weeks Constant medical observation is required over this period

Psychological and Economic Problems

Any person faced with permanent paralysis is prone to undergo a severe mental depression. He must be taught to face his problems and to make the most of his residual capabilities Younger patients with good control of their arm and shoulder muscles can be told that they are no worse off than was the late President Roosevelt after his attack of poliomyelitis and severe paralysis of his lower extremities incurred at middle age. These patients must be inculcated with the will to live and to rise above their handicaps. This will require a prolonged period of training in which their co-operation is all important. The greatest help can be given by previous victims who have made a good recovery by an able psychiatrist and by a chaplain The social service worker can give further help to the patient and his family in their serious financial straits Proper treatment is an exceedingly expensive proposition Our figures show that it will amount to a minimum of $7 000* for the first year the period for which even the patients with relatively uncomplicated cases of paraplegia will have to be hospitalized for treatment and rehabilitation. The unfortunate person with persistent complications and the tetraparetic are fated to remain more or less dependent for life

Elective Neurosurgery and Spinal Fusion

If there is going to be significant recovery of cord conduction, there should be evidence of this within the first month Aside from the surgical indications which have been outlined above exploration of the injured cord or cauda equina during this stage has little to offer In closed injuries without evidence of spinal block exploratory laminectomy should be undertaken only if there is a progressive increase in paralysis or pain from cicatricial adhesions of caudal rootlets However in all cases where the fracture is so unstable that healing will require a prolonged period of immobility it is advisable to do a spinal fusion by the time the patient is in optimal condition. This can shorten the period of complete immobility in bed from 6 to 3 months and will thereby greatly reduce decubitus formation and secondary infection and the tendency to decalcification of bone and urinary-stone formation. Campbell and Meirowsky also claim that late laminectomy is advisable in quadriplegics especially after gunshot wounds since decompression of cervical roots at or above the level of injury may be followed by worth while recovery of function in muscles of the arm or hand even though it has no effect on the degenerated cord itself Lysis of caudal roots is of much more doubtful value, al-

* This is calculated on the basis of Massachusetts General Hospital public ward rates. In the Baker Memorial (the section for patients of moderate means) where consultants fees are included, the minimum comes to about $11,000

though it is occasionally helpful in relieving radicular pain

Physiotherapy

The prevention of stiff joints and contracted muscles and the maintenance of muscle tone should be started by a competent physiotherapist just as soon as the period of spinal shock has passed Much can be accomplished by skilled massage and passive movement of joints Active exercise of intact arm muscles can be started in bed at an early date by a system of pulleys and weights or elastic cords attached to an overhead frame The paraplegic should be encouraged to shift his weight about in bed with his arms and overhead rings and to start more active exercises as soon as there is solid union of the fractures The amount of calcium lost from the skeleton will depend directly on the extent and duration of immobility

Care of the Urinary Tract

Infections of the urinary tract constitute the most frequent and serious of the complications following spinal and caudal injuries In the absence of spontaneous recovery all of the patients with such injuries will have to be on inlying-catheter drainage for a period of months and not all of the patients will regain effective spinal reflex control Wartime experience proved that suprapubic or perineal catheter drainage should almost never be used

As mentioned above (p 188) a 5-cc balloon retention No 16 Foley catheter should be installed as soon as the patient reaches his bed Constant drainage will soon lead to the development of a small, thick walled bladder In order to maintain good storage capacity of the bladder and to facilitate recovery of reflex activity in its muscular wall, it is preferable to start with a two-way system of tubing connected to the catheter by a Y tube One tube is coupled to a graduated intravenous reservoir at the head of the bed the other to a large drainage bottle beneath the bed (Fig 125 *left*) Ordinarily the tube from bladder to drainage bottle is left open and that to the reservoir is clamped off Every 3 hours during the day the drainage tube is clamped and the bladder gradually filled to a volume of 300–400 cc with a sterile solution of boric acid * This simple system is relatively foolproof and is probably the best for small hospitals For the larger paraplegic centers one of the tidal-drainage sets should be put into use at an early date Such an apparatus permits continuous slow-drip filling of the bladder and periodic emptying by siphonage Care must be taken so that the bladder will fill to at least 300 cc. yet never become overdistended This requires frequent check up on bladder tone by cystometry and careful adjustment of the height at which the siphon tubing is set Figure 125 *right* shows Stewart s modification of Munro s apparatus for tidal drainage This is the simplest apparatus to set up It can also be used as a cystometer by clamping off the siphon drainage tube Details for the application of tidal drainage and cystometry will be found in the monographs of Munro and of Prather and Mayfield

As long as a catheter must remain in the bladder the urine will remain more or less contaminated The bacteria most commonly responsible are B proteus pyocyaneus aerobacter aerogenes staphylococci, and the various forms of streptococci The gram negative urea-splitting organisms give rise to an alkaline urine and increase the tendency to stone formation. When there is active infection streptomycin and Chloromycetin® in large doses are the most effective therapeutic agents but the specific sensitivity of the contaminating organisms must always be tested. Courses of mandelic acid may be helpful if the urine

* If the urine is strongly alkaline a sterile 0.5–1 per cent solution of acetic acid should be used to irrigate the bladder Solution M of Suby and Albright can be substituted for boric solution if there is a tendency for calcium phosphate to be deposited on the glass and tubing or to form incrustations in the bladder It consists of:

Citric acid (monohydrous)	32.35 Gm.
Magnesium oxide (anhydrous)	3.84 Gm
Sodium carbonate (anhydrous)	8.84 Gm.
Distilled water q s. ad.	1 000 00 cc

usually be omitted leaving the time factor as the only conditioning stimulus This method of bowel training was originated by Munro and is well described in his original article When there has been complete destruction of the sacral reflex arcs or extensive injury to the musculature of the pelvic diaphragm bowel training is impossible If there is perpetual soiling the best solution is a well-constructed colostomy with a properly fitted colostomy bag

Bedsores and Plastic Surgery

One of the most important principles in the treatment of patients with spinal injuries is the prevention of bedsores The really critical period is during the stage of spinal shock and early stabilization of the fracture when the patient is nearly totally immobile and dependent As outlined above the physician s first concern is to maintain a positive protein-caloric balance and a high level of hemoglobin. The nurse s concern is to keep the sheets clean smooth and dry and to protect the patient from prolonged pressure on bony prominences by frequent turning effective padding and support of the heels and knees Alcohol rubs help by hardening and cleansing the skin gentle massage over the areas most commonly subject to decubitus formation helps by increasing circulation. The slightest abrasion or redness of the skin must be reported to the doctor in charge

Once the skin has broken down local therapy has little to offer except in the smaller most superficial pressure sores In the more extensive deep decubitus ulcers there is at best only slow healing by granulation and ingrowth of thin epithelium which all too frequently continues to break down There appears however to be a close correlation between nutrition and bedsores During World War II a large number of paraplegic sailors and marines who had been wounded in the far parts of the Pacific were cared for in two United States naval hospitals they had been exposed to tropical heat and prolonged passage through a chain of evacuation hospitals and crowded hospital ships. All who suffered from malnutrition had multiple deep bedsores which were covered with gray indolent sloughs These sloughs were replaced by healthy granulations and healing started as soon as the nutritional deficiency and anemia were corrected White and Hamm found that these deep ulcers could be excised and covered by plastic flaps with primary healing. Further work along these lines has corroborated and greatly extended these early operations Cannon and his coworkers have described the most satisfactory modern methods of sliding in full thickness grafts of skin and subcutaneous tissue after removal of necrotic tissue and the underlying bony prominences This seems to be the best way to insure favorable healing and to protect against recurrent ulceration.

Mass Reflexes

Another complication which may develop relatively late in the period of recovery and unless corrected may prevent all progress in rehabilitation is excessive reflex activity The usual spinal reflex response in paraplegia is extension of the hips and knees with an added scissors deformity from adduction. This deformity will prevent ambulation because of the tendency for the legs to cross It can easily be eliminated by obturator neurectomy A far more crippling response is the mass flexion reflex, in which both thighs and knees are drawn up on the slightest stimulus. When these reflexes are severe a patient can no longer sit up in a chair and can lie only on his side in bed. Furthermore the lower abdominal muscles are usually involved as well so that the bladder is likely to empty with each flexor spasm When this is the case recovery of any useful control of the legs is usually impossible and severe bed sores and joint contractures will soon develop together with rapid deterioration of the patient s general health Neurosurgical intervention becomes an absolute necessity since this condition cannot be controlled with muscle relaxant drugs not even with curare

The key to this situation as shown by

Munro is to convert a spastic cord paralysis into the flaccid cauda equina type This can be done with preservation of cutaneous vascular reflexes by cutting the ventral rootlets as they emerge from the conus medullaris If anterior rhizotomy is carried out from the twelfth thoracic through the first sacral rootlets it will interrupt practically all the motor supply to the hip and knee leaving only the second sacral nerve supply to the muscles of the lower leg The second and lower sacral roots should be preserved in order not to impair reflex control of the bladder and rectum and penile erection The operative technique and methods of identifying the nerve roots that are to be sectioned have been best described by Botterell and his colleagues An alternative method that of destroying all the lumbosacral roots by intrathecal injection of absolute ethyl alcohol has been proposed by Shelden and Bors This entails sacrifice of the lower sacral nerves and the sensory fibers which mediate axon reflexes and help adjust cutaneous circulation In one instance at the Massachusetts General Hospital, and in a few others that have been reported this latter method has led to an ascending fatal myelopathy It should therefore be used only in spastic patients who are in too poor condition to tolerate the limited laminectomy required to cut the motor rootlets

Persistent Pain Following Paraplegia

Persistent unbearable pain is fortunately rare following injuries to the cervical and upper thoracic cord However it is not an uncommon complication when the long emerging roots of the conus medullaris and cauda equina become involved in adhesions. This root pain is so severe and continuous that unless relieved it soon leads to narcotic addiction and stops all progress in rehabilitation Nothing can do more harm to the patient s mental and general health than prolonged narcotic medication If no previous lumbar laminectomy has been done it is logical to explore the caudal roots and attempt to free them or to sever the ones most involved in arachnoidal adhesions The roots are likely to be so matted together that this may prove an impossible task and the operation is rarely successful

The surest method for relief of radicular pain is a properly performed high thoracic anterolateral chordotomy This method was used successfully in 6 out of 8 cases of the author s naval and veteran cases and by Freeman and Heimburger in 43 out of 45 cases Chordotomy however will not relieve all varieties of pain Some of these patients undoubtedly have a psychoneurotic background and require psychiatric help Certain types of burning pain have been attributed to abnormal sympathetic action but sympathectomy rarely if ever relieves the patient. When intractable pain is associated with injuries of the spinal cord proper any operation on the spinal cord is almost certain to fail After two such failures at the Massachusetts General Hospital it has been concluded that chordotomy should not be attempted except in cauda equina injuries (below the eleventh thoracic vertebra) Resection of the scarred adherent upper end of the cord has been advocated but it has failed in the two instances in which it was tried at the Massachusetts General Hospital Both patients continued to deteriorate and died. At post mortem examination the rostral stump of the cord was found to be invaded by fibrous tissue infiltrated with inflammatory cells for several inches above the level of amputation Some of the newer modifications of frontal lobotomy can relieve the most intractable varieties of pain but only at the risk of loss of the ambition and initiative that are so vital for the rehabilitation of the paraplegic

STAGE OF REHABILITATION

Six months to a year after a spinal injury the patient should be ready to start on a program of active rehabilitation by this time the vertebral injury will have become stabilized If treatment has been successful he should have recovered a good state of nutrition and should have no open bed

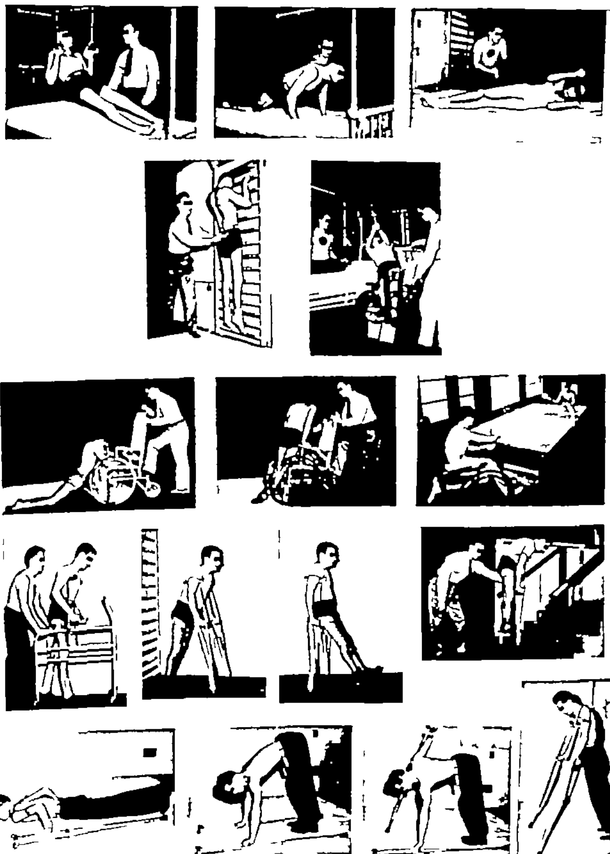


Fig 128 —Physical rehabilitation of paraplegics as used under Dr Deaver s direction at United States Naval Hospital St. Albans New York in 1945 Upper photographs illustrate methods of developing strength and co-ordination in intact arm and shoulder muscles. Patient is taught how to get in and out of his bed and wheel chair Lower photographs show steps in training for crutch and brace ambulation

sores Training in the conditioned reflex control of micturition and elimination of urinary sepsis and of stone formation should be well in hand The patient must be free from crippling mass reflexes and persistent unbearable pain Of equal importance he should have learned to accept his injury and be ready to co-operate in the arduous task of rehabilitation If he is young, active and paralyzed only in the lower half of his body the problem for the physiotherapist is to make him an athlete from the waist up so that he can soon learn to get about with crutches and braces In older less teachable individuals and in the quadriplegics the problem resolves itself into obtaining the most independent existence possible in a wheel chair Training toward these goals can be undertaken more effectively in a large center where there is experienced personnel and equipment as has been thoroughly discussed by Kuhn

The objective is to put the paraplegic through a graduated course of bodily exercises—to teach him balance and physical dexterity so that he can get himself about first from bed to wheel chair and then from wheel chair to the gymnasium mat and toilet seat He will already have started arm shoulder abdominal, and back exercises in bed Now these exercises are increased to include everything he can try to do in a lying or sitting position Next he is fitted with leg braces and if need be hip and back braces that hinge to permit sitting and that lock in standing The patient is then started on walking exercises between parallel bars and in the walker and finally on crutches To complete his course of training he should be taught to pick himself up if he falls to climb stairs to get into an automobile and to drive a car with special hand controls A general idea of these methods as taught to the physiotherapists at the Naval Hospital at St. Albans New York by Dr George G Deaver can be obtained from Figure 128

At the same time if possible the patient should be learning some occupation which he can undertake either a business or some skilled trade with his hands For the paraplegic and occasional partial quadriplegic who finishes the course it will have been a long arduous experience but one that will be a great source of satisfaction to himself his family and all the medical personnel who participated

The degree of recovery of physiological function and rehabilitation in complete spinal injuries which can be obtained by proper training has been summarized best by Munro who has made more contributions to this field and has had a greater experience than any other worker Experience in the Bay State Medical Rehabilitation Clinic of the Massachusetts General Hospital and at the United States Naval Hospital at St Albans has fully corroborated these claims

TABLE 4 —END RESULTS IN 52 INJURIES OF THE SPINAL CORD AND CAUDA EQUINA

Hospital deaths	9 6%
Competent urinary control	70%
Bedsores	37%
Bedsores healed	100%
Severe spasms requiring operation	20%
Neurosurgical relief of severe spasms	100%
Severe pain	10%
Neurosurgical relief of severe pain—chordotomy	33% *
Paraplegic patients ambulant at discharge	85%

Of 52 patients admitted to the Massachusetts General Hospital for injuries to the spinal cord 5 died. Three died in the acute stage—from ascending edema of the cervical cord associated cerebral injury and pulmonary embolism Two deaths in the chronic stage occurred in poor risk cases following operations for severe persistent pain (frontal lobectomy and intrathecal alcohol injection)

* There were 3 patients with severe persistent pain. The first, with a gunshot wound of the cauda equina, had an excellent result following anterolateral chordotomy In the other 2, with injuries of the cord proper division of the spinal pain tracts failed. One was partly relieved later by a limited electrocoagulation of the medial frontal white matter In the wartime experience at naval and veterans hospitals, the results of anterolateral chordotomy seemed to be all that could be desired in 6 out of 7 cases of injuries to the conus medullaris and cauda equina. Anterolateral chordotomy should not, therefore be recommended for the relief of pain arising from injuries to the cervical or thoracic cord, but it is successful in the majority of cases when the pain arises from adhesive arachnoiditis of the roots of the cauda equina.

Of the 47 survivors 18 were transferred to veterans and other hospitals so that no final evaluation can be given. The end results for the remaining 30 patients who completed their rehabilitation program at this hospital are summarized in Table 4 (p 201) The majority of these were younger persons who were able and willing to cooperate in this program This accounts for the unusually high proportion of favorable results

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16  Fractures and Dislocations of the Spine

SPINAL INJURIES may occur in many forms The bodies of the vertebrae may be crushed or the transverse or spinous processes may fracture The laminae and the pedicles in the cervical region may break if there is great violence Vertebrae may be dislocated as a whole or in part Each of these injuries may involve but a single vertebra or several they may occur in the cervical the thoracic or the lumbar region Forcible hyperflexion, hypertension side bending or rotation may result in one or more of these injuries

CORD INJURY

Because the spinal cord is contained within the vertebral column cord and nerve root damage from bone displacement due to injury is an ever present possibility especially in the cervical spine While cord and nerve-root damage does occur at the thoracic and lumbar levels and may be crippling or fatal it is true that severe damage in these areas is the exception The great majority of persons (probably 9 out of 10) who "break their backs" suffer not the slightest cord or nerve-root injury and probably their cords or nerve roots could not possibly have been damaged through the types of fractures which they sustained.

The spinal injuries with which cord or nerve root damage may be associated are clearly defined—they are those which decrease the anteroposterior diameter of the vertebral canal They include all vertebral dislocations (Fig 129) fracture-dislocations (Fig 130) and all bursting fractures of the vertebral body which result in backward displacement of fragments into the vertebral canal (Fig 131) Each is potentially dangerous from the standpoint of injury to cord and nerve roots Each results from major violence such as an automobile crash a mining accident or a fall from a height. Uncommonly forcible hyperextension injuries in the cervical region (especially in the presence of extensive lipping along the posterior margin of the disks) (see p 232 Fig 151) may be complicated by cord damage and, also uncommonly may severe cervical and thoracic disk injuries with retropulsion of disk fragments cause this serious complication

Very uncommonly complete vertebral dislocation may be followed by spontaneous reduction apparently the result of the recoil of the hyperflexed spinal column As

A B C

TRACTION POSTOP 8 YRS POSTOP 8 YRS

Fig 129 —A, a complete anterior dislocation of the sixth cervical upon the seventh cervical vertebra. Symptoms of partial loss of cord function were observed immediately after the injury improvement neurologically was noted very shortly afterward. Reduction was easily completed at operation after several days of halter traction. B result after 8 years Roentgenogram made in maximum flexion. C maximum extension Fusion was solid No neurological symptoms and no complaints Patient carrying on full preinjury activities as a dairyman. (This figure is reproduced from The Journal of Bone and Joint Surgery)



Fig 130 —Lateral (left) and anteroposterior (right) views of fracture-dislocation involving the twelfth thoracic and the first lumbar vertebrae There was immediate complete (permanent) loss of cord function at the level of the injury

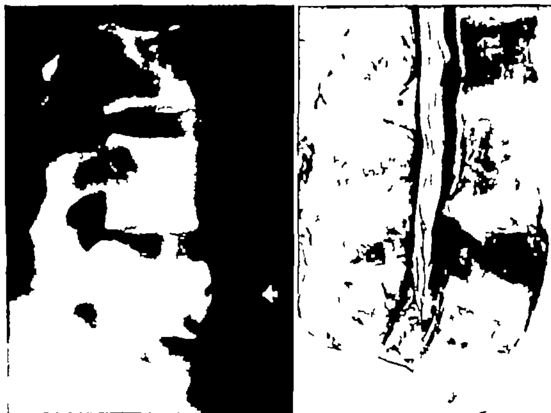


Fig 131 —Left lateral roentgenogram showing a fracture of the body of the fourth lumbar vertebra. A careful check of the outline of the posterior wall of this vertebra reveals backward displacement of a large posterior fragment which might easily be overlooked The patient had fallen 40 feet sustaining multiple injuries and died of shock shortly after admission to the hospital. Right sagittal section of same spine Marked decrease in anteroposterior diameter of vertebral canal and very little space remaining for nerve roots A casual inspection of the x-ray film might result in overlooking a serious condition (This figure is reproduced from The Journal of Bone and Joint Surgery)

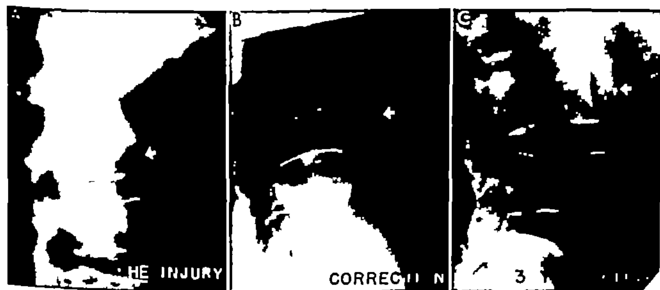


Fig 132.—A, common wedge-compression fracture No dislocation and no fracture of posterior wall of the centrum Vertebral canal is normal The apex of the wedge is usually directed forward B correction of the deformity C 3 years after injury the correction has been maintained

the vertebra is dislocated, complete tran section of the cord may occur yet roent genographically there may appear no other evidence of dislocation than a slight de crease in the intervertebral spacing at the level of occurrence of the dislocation (p 212 Fig 139) Less than complete reduc tion probably occurs spontaneously in some cases Extensive cord injury in the presence of only slight displacement at the time of the first x ray examination is diffi cult to explain on any other basis

In contrast the common wedge-compression fractures of the vertebral body without dislocation (Fig 132) the common trans verse process fractures and the isolated fractures of the spinous processes laminae and articular processes are almost never complicated by cord or nerve-root trauma.

Protection of the Cord and Cauda Equina

The danger of cord injury is present from the moment of injury until the fracture or dislocation has been reduced and the sta bility of the column has been restored. When a disabled person has obviously sustained a major back injury and especially in the presence of a neurological deficit in which the lower extremities are involved it is the responsibility of the trained aid, who is the first to see the injured to take the necessary precautions to protect the cord or cauda equina against further damage This involves gently rolling the patient, without torsion, onto a rigid padded stretcher or frame and keeping the patient in the prone position In this way spinal flexion and extension are both avoided each of which in the presence of disloca tion or a bursting fracture might result in cord or cauda equina compression by di minishing the diameter of the vertebral canal. Transportation to the hospital with out risk of cord damage should be possible by this means

In structure and function, the cervical thoracic and lumbar vertebrae differ mark edly The injuries which occur in each region are therefore different from those in the other regions and different methods of treatment are necessary for each of these *spinal segments*

THE CERVICAL SPINE

Cervical Injuries Dangerous to the Cord

As stated above the cord may be damaged in most of the more common injuries of the cervical spine In a series of 77 pa tients treated for 87 injuries of the cervical spine at the Massachusetts General Hospi tal, there was complete interruption of cord function immediately following the injury in approximately 1 in every 5 patients there was immediate onset of partial loss of cord *function in 1 in every 4 patients* and there was definite evidence of nerve root pressure immediately following the injury in approx imately 1 in every 5 patients In only 28 of the 77 patients was there no sign of loss of cord or nerve-root function as a result of the injury It is a sad commentary that in 1 in every 10 patients the symptoms of cord compression or an increase of cord symptoms developed subsequent to the time of original injury—during emergency care during the time when the diagnosis was being established during definitive treatment, or following reduction (Table 5)

TABLE 5 —Time of Onset of Neurological Symptoms

	Patients No.	Per Cent
Late onset of increase of cord symptoms (all were anterior dislocations)	8	10
Immediate onset of symptoms of complete cord interruption	15	20
Immediate onset of symptoms of incomplete cord interruption	19	25
Symptoms of nerve-root pressure only	15	20
No neurological symptoms	28	36
Total	77	101

Bursting fractures of the vertebral body (longitudinal compression) commonly result in backward displacement of bone frag ments (Fig. 133) and often there are im

mediate symptoms of cord compression A S Taylor Schneider and Kahn and Rogers have reported the late onset of cord symptoms after failure to correct backward displacement of bone fragments Relief of symptoms followed decompression Elsberg Stookey Cramer and McGowan Bucy and associates and Barnes demonstrated that hyperflexion injuries of the cervical spine without vertebral fracture or dislocation may cause retropulsion of fragments of the intervertebral disk. It is also well known that disk displacements disabling neurologically may occur without specific injury Anterior dislocation or unilateral rotatory dislocation may also result in cord damage (Figs 129 and 134) In such dislocations Barnes has shown that cord compression is not possible until the dislocation of one or both of the inferior articular processes is complete and they lock In the presence of complete anterior dislocation there may be no cord damage whatever (Fig 135) However Barnes showed that if the spine is extended while one or both of the inferior articular processes of the dislocated vertebra are anterior to the superior articular processes of the vertebra below the lower border of the vertebral arch may move downward and forward into the vertebral canal and compress the cord from behind (Fig 136) Posterior dislocation (Figs 137 and 149) and hyperextension injuries may also result in cord damage A R Taylor and Blackwood demonstrated at autopsy that posterior dislocation of a

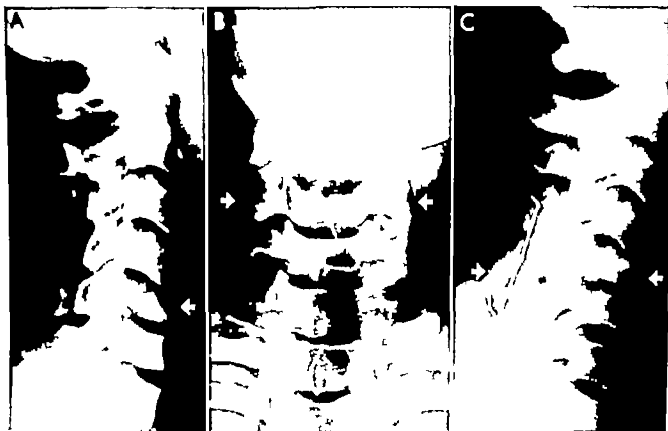


Fig 133 —A, a bursting fracture of the fifth cervical vertebra the result of diving into shallow water The posterior fragments have been displaced backward into the vertebral canal. B anteroposteriorly the centrum appears split vertically in the sagittal plane The lower part appears jammed into the concavity of the upper surface of the vertebral body below In the superior portion there is definite lateral displacement of fragments the superolateral processes do not clasp the body above but have been pushed laterally C result 2 years later Fusion was solid. There was complete and lasting freedom from cord symptoms (at 11 year follow up) no pain and full preinjury activities (This figure is reproduced from The Journal of Bone and Joint Surgery)

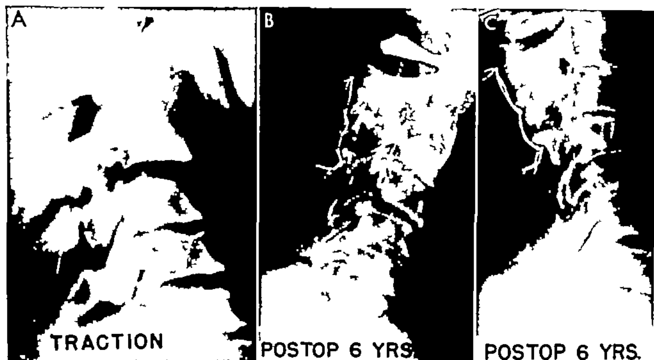


Fig 134 —A lateral view showing a unilateral rotatory dislocation of the second upon the third cervical vertebra. Symptoms of partial interruption of cord function were noted immediately after the injury but disappeared in a few days Reduction was attempted by skull traction without success but was achieved at open operation B the result 6 years later Fusion was solid. Maximum flexion C maximum extension The patient resumed full preinjury activities as a truck driver in 10 weeks (This figure is reproduced from The Journal of Bone and Joint Surgery)

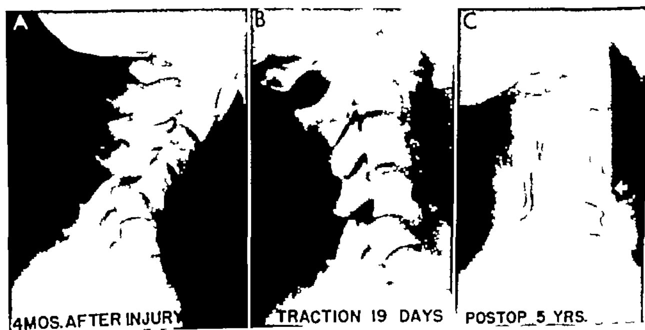


Fig 135 —A, anterior dislocation of the fourth upon the fifth cervical vertebra 4 months after an automobile accident. Patient had received no treatment No symptoms of loss of cord function B strong skull traction resulted in only slight improvement in position. C result after 5 years Fusion was solid. Full preinjury activities No loss of cord function. (This figure is reproduced from The Journal of Bone and Joint Surgery)

cervical vertebra may cause transverse compression of the cord (This occurred in 1 patient in the Massachusetts General Hospital series of 77 patients) The dislocation may undergo spontaneous reduction without any immediate roentgenographic evidence of injury Taylor also demonstrated on the cadaver that forward vertebral osteophytes and cord degeneration

In order to explain the cord damage which sometimes occurs in the absence of definite x ray evidence of injury to the vertebral column it was long held that a dislocation had taken place immediately followed by spontaneous reduction The re

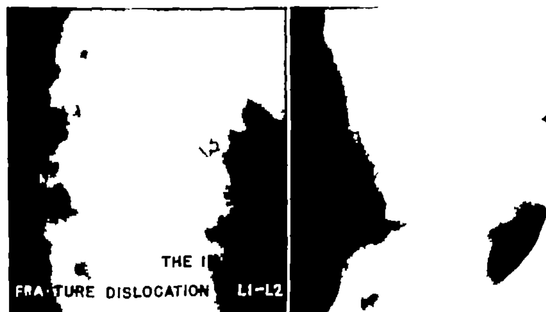


Fig. 136 —*Left* anterior fracture-dislocation of the first upon the second lumbar vertebra. The patient had been thrown from an automobile There was little immediate evidence of root pressure A few days later he was transferred from a distant hospital with an increase in motor and sensory paresis in both lower extremities He could still move his lower limbs Reduction was attempted by traction-extension without anesthesia. *Right* showing the extent of the replacement obtained The flexion element of the dislocation had been corrected but replacement posteriorly had been blocked by the superior articular processes of the vertebra below At this point there was an abrupt and almost complete motor and sensory loss in the lower extremities Open operative reduction was immediately carried out under local anesthesia At operation, when the vertebral arches were exposed the inferior articular processes of the dislocated vertebra lay anterior to the superior processes of the vertebra below As a result of the extension, the arch of the dislocated vertebra had moved downward and slightly forward decreasing the diameter of the canal and compressing the dura and cauda equina between its lower edge and the posterosuperior margin of the vertebra below Finally the posterior elements of the two vertebrae had locked preventing further extension The locked processes were disengaged by spinal flexion were manipulated into normal alignment and then reduced by extension thus decompressing the cauda equina. Subsequently there was full return of motor and sensory function.

bulging of the ligamentum flavum through hyperextension of the cervical spine especially when it occurs opposite a marginal osteophytic ridge on the front wall of the canal, may cause compression of the cord. There is ample autopsy and clinical evidence to support this finding (Fig 138) Bedford Bosanquet, and Russell have reported causal relationship between cervical

duction was assumed to be due to recoil of the column resulting from muscle action the dislocation was believed to cause the cord damage No definite evidence in support of this explanation appears to have been reported, and the concept has been widely disclaimed as highly improbable In 1939 however autopsy findings were reported (by Rogers) in a thoracic spine

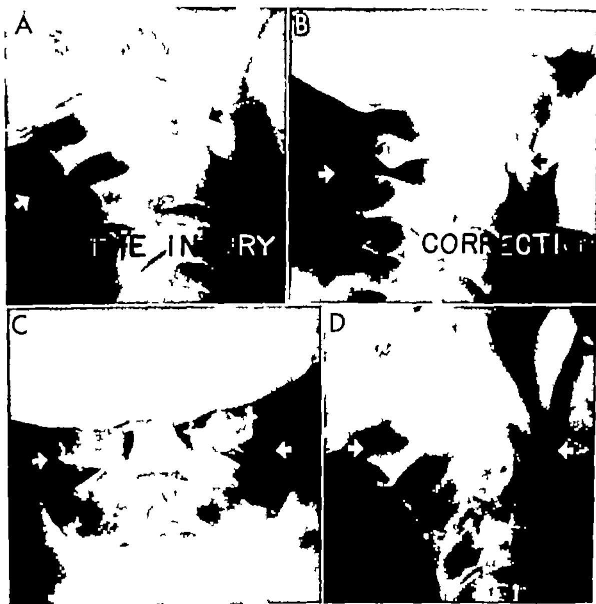


Fig 137 —A, lateral roentgenogram of a posterior dislocation of the atlas upon the second cervical vertebra with fracture of the odontoid process and lateral articular processes of the second cervical vertebra Patient had fallen downstairs landing on her face This had occurred shortly before admission to the hospital. There was evidence of almost complete loss of cord function B showing reduction obtained by skull traction C and D same vertebrae 7 years later While greatly improved neurologically the patient was still unable to work, although she could care for herself in an institution for the partially disabled. Range of cervical motion was normal (This figure is reproduced from The Journal of Bone and Joint Surgery)

which can be interpreted on no other basis than that spontaneous reduction occurred following dislocation (Fig 139) It is also apparent from Figure 139 that while the cord may have been compressed during the phase of dislocation the obvious cause of compression is the retropulsion of disk fragments into the vertebral canal The roentgenograms show narrowing of the intervertebral space It is well known however that backward displacement of disk tissue can occur without narrowing of the involved disk space

Emergency Treatment

It is the responsibility of the trained aide who is first called on to care for the patient

with a neck injury to institute emergency measures which will protect the cord Traction applied in the direction of the long axis of the spine in the neutral position will protect the cord which has escaped injury at the time of or subsequent to fracture or dislocation of the cervical spine—at least in a high proportion of cases—and will prevent further cord injury when damage has already occurred (Table 6) Traction is applied to the cervical spine as first aid by means of an adjustable traction neck brace (Fig. 140) The brace is so constructed that it exerts a constant pressure against the chin and occiput in the cephalad direction and against the chest and shoulder girdle in a caudad direction thus exerting traction on the cervical spine For over a decade such a brace has been successfully used at the Massachusetts General Hospital as a routine measure to protect the cord in the presence of injury of the cervical spine The brace is worn at all times when the patient is being moved from place to place as in transfer to and from the x ray department to and from surgery and during the application of tongs for skull traction During these years no cord injury has occurred in any of the patients wearing one of these braces

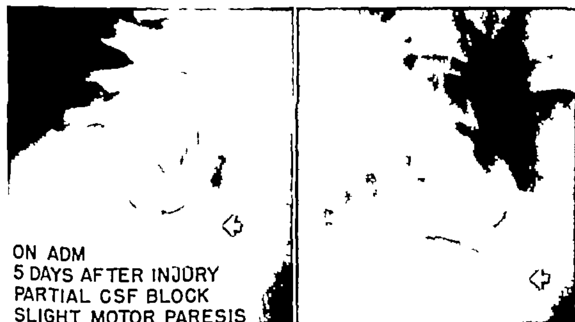


Fig. 138 —*Left* anterior dislocation of the fifth upon the sixth cervical vertebra in an old man with *marked hypertrophic changes (marginal lipping)* *Right* while under halter traction for about 1 hour he became paraplegic and a complete spinal fluid block developed The x ray film shows reduction and hyperextension at the site of injury (This figure is reproduced from The Journal of Bone and Joint Surgery)

TABLE 6 —RESULTS OF SKULL TRACTION IN THE REDUCTION OF FRACTURES AND DISLOCATIONS AND THE PROTECTION OF THE CERVICAL SPINAL CORD

Number of patients	48	
Total time of traction	326 weeks	
Average time of traction	6 8 weeks	
Cord injury during traction (patients)	0	
Complete reduction (patients)	29	37 (77%)
Prior complete reduction maintained (patients)	8	
Satisfactory reduction maintained (patients)	6	(12.5%)
Failure of reduction (patients)	5	(10%)

The traction force must be applied in the direction of the long axis of the neck in the *neutral position* The importance of keeping the direction of the traction in neutral cannot be overemphasized The term "neutral," as applied to the cervical spine may be defined as that position in which there is a slight amount of extension—that is one of slight lordosis Since both flexion and ex

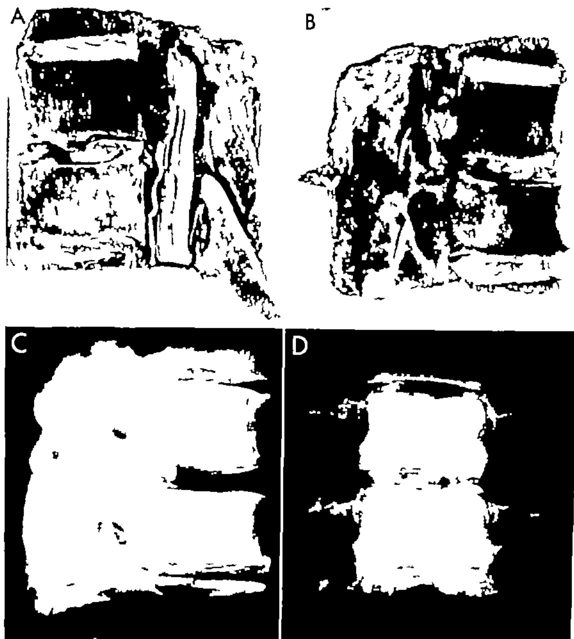


Fig 139 —A sagittal section of an autopsy specimen of decalcified sixth and seventh thoracic vertebrae (Warren Museum, Harvard Medical School specimen No 12736) The patient aged 43 had fallen four stories from a roof to the sidewalk below He had sustained a fractured skull remained unconscious and died on the third day after the injury There is complete rupture of all binding ligaments and muscles The sixth intervertebral disk is shattered Fragments of the sixth disk and a hematoma are lodged between the dura and the posterior wall of the upper of these two vertebrae Above the disk fragments are seen lodged in the vertebral canal as high as the superior surface of the sixth vertebral body below disk fragments, including a fragment of the cartilaginous end plate are found as far distally as the sixth disk, to the remnants of which they are still attached by a band. The posterior longitudinal ligament has been torn across opposite the middle of the sixth centrum The mass of disk fragments presses upon the crushed cord. B paramedial sagittal section through one of the posterior articulations. C and D roentgenograms of the specimen. No evidence of fracture in the vertebrae Marked anterior dislocation of the sixth upon the seventh thoracic vertebra must have occurred reduction having taken place spontaneously through the recoil of the column when the force had been spent (This figure is reproduced from The Journal of Bone and Joint Surgery)

tension from the neutral position have been demonstrated to cause cervical-cord compression in injuries of the cervical spine flexing and extending forces are to be avoided at least until the nature of the injury has been determined

For the brace to be effective moderate pressure is necessary on the chin and occiput For this reason the brace can be worn effectively for a few hours only The

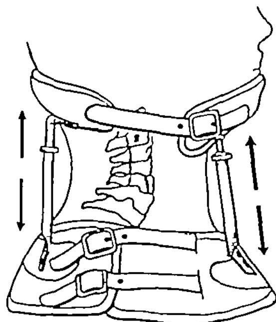


Fig. 140 —Cervical traction brace used in first aid and at all times when the patient is being moved about before the neck is stabilized (This figure is reproduced from The Journal of Bone and Joint Surgery)

pressure is then lessened for a short time during which time the patient must be inactive When traction is to be resumed the brace is first shifted slightly to change the points of maximum pressure

The traction brace must be worn from the earliest possible moment after the injury until the patient is safely in bed in the hospital and skull traction has been applied. Neck injuries require that the patient remain recumbent until stability has been restored.

When there is sensory paralysis hard objects such as pocket knives and pliers must be removed from pockets as soon after injury as feasible in order to prevent the development of pressure necrosis

Diagnosis

The diagnosis is made on the basis of the x ray and neurological examinations An teroposterior lateral and right and left oblique roentgenograms of the entire cervical spine as well as a roentgenogram made through the open mouth to show the odontoid process are essential A surgeon must be present when the roentgenograms are made because of the danger of cord injury as the patient is moved The patient should not leave the x ray department until satisfactory films have been made

Treatment

The first objective in the definitive treatment is the protection of the spinal cord during reduction and stabilization When the safety of the cord has been reasonably assured through properly applied and adequate skull traction reduction of the fracture or dislocation becomes the surgeon s next responsibility In attempting reduction, restoration of the anteroposterior diameter of the vertebral canal (commonly decreased by the injury) to as near the normal as possible is of primary importance To restore the injured vertebra to a normal or stable relationship with the vertebrae immediately above or below is the next important step Finally measures are undertaken to assure lasting stability in the injured spine either through internal fixation and fusion or by adequate external fixation until healing is complete

Among the key articles in the field of skeletal traction for the reduction of fractures and dislocations of the cervical spine are those by Crutchfield Hoen McKenzie and Barton.

Internal fixation by means of silk or wire loops binding together the vertebral arches and posterior fusion by grafting in order to stabilize the cervical spine at the site of injury have been practiced occasionally for

many years Cone and Turner in 1937 reported a substantial series of cervical spine injuries treated by fusion with excellent results In 1942 a series of 11 cases of fracture and dislocation of the cervical spine in which wire internal fixation and spine fusion had been employed to stabilize the injured cervical spine was reported by Rogers

Skull Traction

The spinal cord is protected when the cervical spine is under skull traction. That this is true is attested by the fact that cord injury did not occur at the Massachusetts

TABLE 7 —INJURY DISTRIBUTION

	No. of Patients	No. of Lesions	Per Cent
Wedge-compression fracture	6	9	10
Bursting fracture of atlas	2	2	2
Bursting fracture of vertebral body	10	12	13
Unilateral rotatory dislocation	8	9	10
Anterior dislocation	29	31	34
Anterior fracture-dislocation	8	9	10
Fracture of ankylosed spine	1	1	1
Posterior dislocation	2	2	2
Hyperextension injuries	2	2	2
Posterior fracture-dislocation (including odontoid process)	2	2	2
Anterior fracture-dislocation (including odontoid process)	2	2	2
Fracture of the odontoid process	9	9	9
Unknown	3	3	3
	84*	93†	
	− 7	− 6	
Total	77	87	100

* Seven patients having two different injuries were counted twice.

† Six lesions were counted twice 2 anterior and 2 posterior fracture-dislocations of atlas on axis, and 2 hyperextension injuries.

General Hospital in a single instance in 48 patients in whom the neck was under skull traction for a total of 326 weeks. The injuries in these patients represented almost every common type of fracture and dislocation of the cervical spine (Table 7) In 43 of the 48 patients (90 per cent) complete reduction of the fracture or dislocation or a satisfactory position* or bone fragments was obtained as a result of the traction applied primarily to protect the cord. When reduction is followed by internal fixation and fusion skull traction is usually unnecessary after a few days At the Massachusetts General Hospital the most satisfactory devices for applying skull traction were found to be Barton tongs and Hoen wires

The traction cord is passed through a pulley attached to a trolley which can move freely on a horizontal track fixed to the adjustable head element of the bed (see p 187 Fig 124) This device designed by W A. Rogers makes it possible for the patient to lie on either side or on his back. He may also be raised to the semi-upright position when the head element of the bed is turned up In this position he may read and feed himself with comparative ease The period of recumbency is therefore less tedious and the nursing care is facilitated especially in patients with cord injury in whose management frequent turning is important.

Anatomical reduction was effected by means of skull traction in 29 of the 48 patients upon whom it was used at the Massachusetts General Hospital. In the patients in whom reduction was complete there were 14 anterior dislocations 7 bursting fractures of the centrum 1 bursting fracture of the atlas 1 wedge-compression fracture of the vertebral body 3 fractures of the odontoid process with displacement, 1 posterior dislocation, and 2 fracture-dislocations In 8 other patients anatomical restoration was maintained by skull traction. In 1 patient partial anterior dislocation had been present for 7 months skull traction was attempted and the dislocation was promptly reduced (Fig 141) However skull traction failed to reduce a partial anterior dislocation present for 4 months (Fig. 135) Reductions were arbitrarily considered satisfactory when the roentgenograms showed that there was less than 3-mm

* One may arbitrarily accept as a satisfactory position one with less than 3-mm decrease of the lumen of the vertebral canal

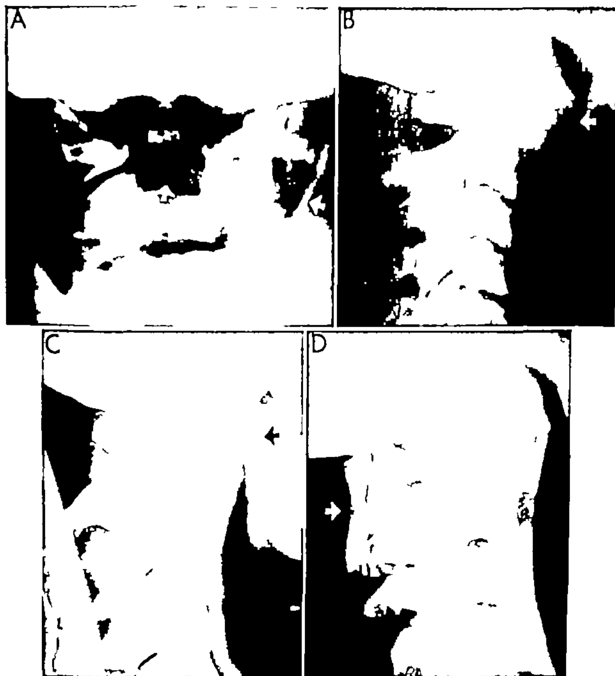


Fig 141 —Anteroposterior (A) and lateral (B) views showing anterior dislocation of the atlas upon the second cervical vertebra with nonunion of a fracture of the odontoid process The injury had occurred 7 months earlier and the diagnosis had not been made Neurologically the examination was negative C reduction was by skull traction The roentgenograms were made after 10 days of traction D result 3 years after the operation There was solid bone fusion the patient was symptom-free and he had been working for 2½ years The fracture of the odontoid process did not unite (Reproduced from Journal of Bone and Joint Surgery 1957)

decrease in the anteroposterior diameter of the vertebral canal Such reduction was brought about in 6 other patients In the total series there were 5 failures of reduction by skull traction 4 were in patients with unilateral rotatory dislocations and 1 failure occurred in a patient with an anterior dislocation of 4 months duration (Table 6)

There were 8 patients in whom fractures or dislocations were reduced by halter traction, by open reduction or simply by positioning (3 partial dislocations) and in whom reductions were then maintained without loss by skull traction (Table 6)

Open Reduction

It is becoming more generally recognized that delayed onset of neurological symptoms or failure to regain function in damaged cords following injury to the cervical spine is causally related to the decrease in the anteroposterior diameter of the neural canal. This decrease in diameter is caused by displacement of bone disk, or ligament, as observed by clinicians for a number of years More recently the subject has been studied by Kahn and by Schneider and Kahn Kahn pointed out that the dentate ligaments may prevent free movement of the cord posteriorly away from bone or disk fragments which have been displaced backward into the vertebral canal by injury It may be demonstrated by anatomical dissection that the dural prolongations along the spinal nerve roots resist backward displacement of the dura. Since the dentate ligaments are attached to the dura the cord cannot move posteriorly away from the protrusion. When, however these ligaments are divided in the vicinity of a fragment of bone or disk protruding posteriorly the cord can be seen to move backward and may by this means be decompressed Any definite decrease in the anteroposterior diameter of the bony canal must therefore be corrected when possible Correction is brought about by reducing the fracture or dislocation by means of either skull traction or open operative manipulation In the presence of irreducible bone displacement, Schneider and Kahn advocated laminectomy followed by division of the dentate ligaments on either side in the vicinity of the displacement and by fusion.

Open reduction was undertaken in 7 of the 77 patients in the Massachusetts General Hospital series In 4 of these 7 patients definite decrease of the front-to-back diameter of the vertebral canal had persisted despite skull traction. Three had unilateral rotatory dislocations and 3 had anterior dislocations In 1 patient there was a free vertebral arch fragment Open reductions were complete in 6 and almost complete in 1 the lumen of the vertebral canal being restored to normal in each instance In one of these patients there was delayed onset of cord symptoms due to manipulation during laryngoscopic tracheal intubation a method henceforth abandoned Two of the patients who underwent open reduction had cord symptoms at the time of operation each regained complete cord function and are known to be neurologically normal for 2–12 years following operation The dislocation had been present in 1 of the 7 patients for 4 months prior to the reduction (Fig 135)

The operation of open reduction is performed with the patient prone the head resting on the attachment of the table used in cerebellar surgery Skull traction is maintained throughout. General anesthesia is administered endotracheally through an intranasal tube Laryngoscopic tracheal intubation must not be used. Identification of the injured vertebra during the operation does not always prove easy The prominence of the spinous processes of the second sixth and seventh cervical vertebrae makes possible close approximation to the injured bone Exact identification is then obtained roentgenographically by the use of a metallic marker (This has been routine practice at the Massachusetts General Hospital since 1940 when an injured vertebra was erroneously not included in the fusion) The neural arches of the involved vertebrae including the articular processes are exposed subperiosteally Reduction is

then effected usually by gentle instrumental manipulation applied through the spinous processes If necessary the head may be manipulated by an assistant the appropriate maneuvers being clearly indicated by inspection of the exposed neural arches In long standing anterior dislocation (Fig 135) it may be necessary in order to accomplish reduction to lever with an appropriate instrument the displaced articular processes back into normal relationship with their articulating fellows As an alternative gentle instrumental manipulation may be applied to the spinous processes following partial excision of one or more articular processes

Wire Internal Fixation and Fusion

Following reduction excellent internal fixation is provided by binding together with wire the bases of the spinous processes of the injured vertebrae and those of the vertebrae next above and below Bone grafts are applied to the exposed cortical surfaces (which have been denuded of periosteum) between the laminae and between the spinous processes Stabilization by this means assures the lasting safety of the cord Solid bone fusion was accomplished by means of this technique in 36 of 39 patients

Internal fixation and fusion achieved by this procedure prevent recurrence of displacement shorten the period of recumbency in traction and allow the patient to be up and about and to leave the hospital at an early date Patients with loss of cord function can be mobilized much sooner Early resumption of light activities is permitted and resumption of full preinjury activities without too great a loss of time is made possible in a high proportion of cases (Table 8) This form of stabilization has protected the cord from attrition in all patients operated on in this series

In the 39 patients each vertebra which had been fractured or dislocated was fastened to the adjoining injured vertebra and to the next normal vertebra above and below in a normal or nearly normal relationship Fixation is accomplished by means of figure-of-eight loops of 22 gauge stainless steel wire which bind together the bases of the spinous processes The wire prevents hyperextension and makes it possible for the posterior articulations to block flexion Autogenous cancellous iliac bone grafts in the form of 3×1×0 3-cm slabs are then packed in layers bridging the intervals between the laminae about the bases of the spinous processes under the wires and between the spinous processes

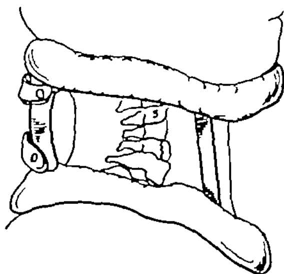


Fig 142.—Convalescent neck brace worn after operation for internal fixation and fusion until bone fusion is solid (Reproduced from Journal of Bone and Joint Surgery 1957)

All patients who are free of cord symptoms at the time of operation (there were 33) are allowed to be up and about in a few days to several weeks after the date of operation On becoming ambulatory they are equipped with a restraining cervical brace (Fig 142) which is worn uninterruptedly until solid fusion has been demonstrated beyond any doubt The brace is designed and worn as a restraint to prevent wide ranges of motion of the neck It is not intended to immobilize By restricting motion all undue stresses on vertebral cortices at the points of contact with the wire loops are avoided Ryerson and Christopher showed that unrestrained motion will result in erosion of the bone by the wire and that stability will be lost before bone fusion has taken place

All of the patients in the Massachusetts General Hospital series who were free of symptoms of cord compression left the hospital in the ambulatory state

End-Results

The result in each patient was deter mined by physical and x ray examination (at 1–12 years after the beginning of de finitive treatment the average being 5 years) (Table 8) Fourteen of the 77 pa tients died from complications resulting di rectly from involvement of the cord Death occurred from a few hours to 7 months after the injury

TABLE 8 —Results of Treatment of Skeletal Injury

	Including Internal Fixation-Fusion (39 Patients)			Not Including Internal Fixation-Fusion (33 Patients)		
Anatomical reduction (obtained or maintained)						
By skull traction	19			14		
By open operation	6	29			21	
By halter traction	4			7		
Satisfactory restoration of lumen of vertebral canal (decrease less than 3 mm.)			31			31
By skull traction						
By open operation	1			5		
By halter traction	1	2			10	
Present in old injury				5		
Unsatisfactory restoration of lumen of vertebral canal (decrease more than 3 mm.)			7			2
By skull traction						
By halter traction						
Present in old injury			1			
Stability						
Operative bone fusion	37					
Time of bone fusion	8–12 weeks	37 (95%)			9 (36%)	
Spontaneous (interbody) fusion				9		
Time of spontaneous interbody fusion				4–18 mo		
Instability						
Failure of operative fusion	2 (5%)					
Recurrence of dislocation				4 (16%)		
Complications	2 (5%)			2 (6%)		
Anesthetic death	1 (laryngoscopic intubation)			1 (inadequate anesthesia)		
Temporary aggravation of neurological symptoms	1 (laminectomy—old injury)					
Halter traction restlessness death				1		
Return to work	33 of 34 (97%)			22 of 27 (81%)		
Time of return	5 4 mo			9 mo.		
Irreparable cord injury or old age	5			6		

Internal Fixation with Fusion

Thirty nine patients were treated with internal fixation with fusion

Fusion —The criterion of solid bone fusion in cases of operative stabilization is absence of demonstrable change in the relationship of the fused vertebrae to each other in two sets of comparable lateral roentgenograms made in maximum flexion and maximum extension 1 week apart (Fig 129) In all but 2 patients in this series fusion took place The time required for fusion was 8–12 weeks usually 8 weeks.

Recurrence.—No patient in whom the involved vertebrae were fused together sur

gically has suffered a recurrence of dislocation or of deformity

NEUROLOGICAL STATUS —In no patient who was free from neurological symptoms before operation did such symptoms develop subsequent to solid fusion All patients who had neurological symptoms indicative of partial loss of cord function at the time of operation became so improved that their neurological status was nearly normal or became normal

One patient had had four episodes of quadriplegia during the preceding 19 years

TABLE 9 —COMPLETE AND ALMOST COMPLETE INTERRUPTION OF CORD FUNCTION

	Improvement to Normal or Almost Normal	Moderate Improvement	Slight or No Improvement	Return to Work	Death during or after Treatment	Death before Definite Results of Treatment
Anatomical reduction and operative or spontaneous fusion (9 patients)	5 (55.5%)		4 (44.4%)	4	2 (Cord death, 1 pneumonia 1)	
Satisfactory reduction without operative or spontaneous fusion (11 patients)	1 (9%)	1 (9%)	9 (82%)	1	8 (Cord death 5 urinary-tract infection 2 pulmonary infarct, 1)	
Unsatisfactory* reduction but operative or spontaneous fusion (1 patient)	1					
Without result from treatment (4 patients)						4
Total (25 patients)	7 (28%)	1 (4%)	13 (52%)	5	10	4 (16%)

* More than 3-mm. decrease in diameter of vertebral canal.

because of a chronic progressive anterior dislocation of the atlas upon the second cervical vertebra A laminectomy was done the dura was not opened Fusion was effected of the occiput to the second and third cervical vertebrae Immediately after surgery he was again quadriplegic Slowly thereafter his condition improved becoming nearly normal At the last follow up examination 7 years after surgery he was symptom free with the exception of cervical motion which was limited to a few degrees In this patient there were also advanced hypertrophic arthritic changes He was 64 years of age and had retired (See Tables 9 10 and 11)

PAIN —None of the 39 patients who underwent fusion complained of neck pain subsequent to wound healing

FUNCTIONAL RESTORATION —This was complete in the range of cervical motion consistent with age in all except 4 of the patients Two patients underwent fusion of the occiput to the first second and third vertebrae these retained 10 and 20 per cent of rotation respectively Two patients who underwent fusion of the first and second vertebrae retained 50 per cent of rotation

RETURN TO WORK —Of the 39 patients who underwent operative fusion 33 resumed work in an average of 5½ months Of the remaining 6 3 were quadriplegic and 3 had retired from work on account of age

FAILURE OF FUSION —Fusion failed in 2 of the 39 patients In one the wire used for internal fixation broke A considerable por

TABLE 10 —PARTIAL INTERRUPTION OF CORD FUNCTION

	No of Patients
Satisfactory reduction and operative or spontaneous fusion	10
Improvement to normal or almost normal	8 (80%)
Marked improvement	1 (10%)
Moderate improvement	1 (10%)
Return to work	8 (av 6 mo)

tion of one of the vertebral arches had been removed as a free fragment which was felt to be a menace to the cord The patient had no further trouble from the injury despite the failure of fusion The other patient a woman of 62 years had advanced degenerative arthritic changes in the cervical spine with marked lipping Her neck had been accidentally hyperextended during laryngoscopic intubation for endotracheal anesthesia She was found to have complete interruption of cord function following the operation and died the next day Laryngoscopic intubation was forthwith stopped in this form of surgery of the cervical spine and there has been no further trouble since

Intranasal tracheal catheterization has proved safe and effective in 15 subsequent patients

Operative Fatality —One patient suffered fatal cord damage from cervical hyperextension incidental to laryngoscopic intubation

Nonoperative Fatality —One patient who had operative fusion and who was quadriplegic succumbed to pneumonia 2 years after the operation

Treatment without Surgical Fusion

Of the 38 patients who were treated without surgical fusion 6 died of cord damage (sustained at the time of injury) within a few days of admission to the hospital

Reduction —Anatomical reduction was achieved or maintained in 21 of the remaining 32 patients—in 13 by means of skull traction and in 7 by halter traction. Incomplete reductions but stable relationships were achieved or maintained in 10—in 5 by means of skull traction and in 5 by halter traction or by brace Incomplete reductions could not be improved in 2 patients—one lesion was of long standing and one was accepted by the patient

Recurrences —In spite of external fixation, there was recurrence in 4 of the 32 patients In each instance the injury was an anterior dislocation in 3 of the 4 patients the sixth vertebra was dislocated upon the seventh in 1 patient the fifth vertebra was dislocated upon the sixth

Spontaneous Fusion — Spontaneous fusion occurred between adjacent injured vertebral bodies in 8 of the 33 patients and was probable in a ninth The time of interbody fusion could not be determined with precision for a number of reasons Fusion had unquestionably taken place at 3 months in 1 patient and at 18 months in another (the extremes) The average time for 7 of the patients was probably about 8 months In 1 patient interbody fusion occurred not only at the site of injury but at the second disk above and the disk next below

Nonunion —Nonunion occurred in 2 patients Both had sustained fractures of the odontoid process All other fractures united

Pain —No patient complained of local or referred pain in this group once the injury had healed

Functional Restoration —There was a complete range of cervical motion con

TABLE 11 —Nerve Root Compression

	Improvement to Normal or Almost Normal	Slight Residual	Moderate Residual	Return to Work
Satisfactory reduction and operative or spontaneous fusion (20 patients)	16 (80%)	2 (10%)	2 (10%)	19 (95%) (Av 6.5 mo.)
Satisfactory reduction without operative or spontaneous fusion (2 patients)	1	1		2 (Av 13 mo)
Unsatisfactory reduction but operative or spontaneous fusion (2 patients)	2			2 (Av 9 mo)
Total (24 patients)	19 (79%)	3 (12.5%)	2 (8%)	23 (96%)

sistent with age in all patients who survived the injury As degenerative arthritic changes developed with advancing years the range of motion became correspondingly limited There seemed however to be no limitation directly attributable to the injury itself

RETURN TO WORK —Of the patients who survived the injury 22 returned to work in an average of 9 months

CORD INJURY DURING TREATMENT — This occurred in 2 patients due to restlessness following traction

One of these patients was 64 years of age. He had fallen downstairs 1 week before admission to the hospital and had been in bed since because of pain in the neck On entering the hospital he had no sign of cord injury there was weakness of hand grip bilaterally Roentgenograms disclosed a partial anterior dislocation of the fifth upon the sixth cervical vertebra and the cervical spine was the seat of advanced degenerative arthritis with marked lipping Halter traction was applied An hour later signs of complete interruption of cord function had developed at the level of the fifth cervical vertebra. There was a partial block to the flow of cerebrospinal fluid Roentgenograms made at that time showed that reduction had taken place There was actual hyperextension of the fifth upon the sixth cervical vertebra and marked lipping on the inferior margin of the fifth cervical vertebra posteriorly and on the superior margin of the sixth vertebra posteriorly Cord function was not re-established and the patient died 5 weeks later No autopsy was performed He had been very restless while under halter traction and it seems probable that the cord was compressed between a bulging ligamentum flavum behind and marked marginal lipping anteriorly due to voluntary hyperextension Had skull traction been employed this fatality would probably have been avoided

It has been concluded that halter traction strong enough to be effective is too uncomfortable uncontrollable restlessness may ensue and be disastrous

The second patient 75 years old fell 2 days before admission to the hospital injuring his neck There was no evidence of cord or root compression Roentgenograms disclosed an anterior dislocation of the fifth upon the sixth cervical vertebra Hoen wires were introduced into the skull without incident until the skin sutures were being placed where the local anesthetic had evidently worn off The patient whose neck had been stabilized with a Thomas collar during the insertion of the Hoen wires suddenly thrashed about At once he went into shock and was found to have become quadriplegic The next day the dislocation was found to have been reduced The skull traction maintained the reduction and allowed adequate nursing care with frequent changes of position The patient was comfortable at all times The patient died 6 days after the onset of quadriplegia which was in all probability due to violent extension of the dislocated cervical vertebra

CAUSE OF DEATH —Of the group of 38 patients treated without surgical fusion, 13 died as a result of the injury Three died of cord damage within a few days of the injury before results of treatment could be noted Three died within 1–6 days of cord damage despite treatment Two died suddenly of massive pulmonary infarction—1 patient at 11 days after injury and the other at 2 weeks Two in whom the bladder was paralyzed because of the cord injury died of urinary tract infection One died of cardiac failure and 2 died as a direct result of definitive treatment—1 patient from halter traction and the other from failure of local anesthesia during the application of skull traction

MORE COMMON TYPES OF CERVICAL-SPINE INJURY

The common injury of the cervical spine is anterior dislocation of a vertebral body The less frequent injuries are bursting fractures of a vertebral body unilateral rotatory dislocations anterior fracture-dislocations and uncomplicated wedge-compression fractures Still less common appear to be fractures of the odontoid process fracture-dislocations of the atlas upon the second cervical vertebra, bursting frac

tures of the atlas and posterior fracture-dislocations (Table 7)

Wedge-Compression Fracture

Wedge-compression fracture of a cervical vertebral body is caused by violent hyperflexion of the cervical spine the mechanism being essentially the same as that in wedge-compression fracture of the lumbar spine Uncomplicated by dislocation of the vertebra next above this injury was found *9 times in 6 patients in this* series of 87 injuries of the cervical spine (Fig 143) Four of the patients having wedge-compression fractures remained free of cord symptoms *One patient who had* sustained wedge-compression fractures of the fourth and fifth vertebrae had marked deformity in each of these vertebrae Immediately following injury he *had almost* complete motor and sensory loss below the fractures Within a few weeks there was nearly complete recovery of cord function. In the other patient who had a wedge-compression fracture of the sixth vertebra there was immediate onset of partial interruption of cord function Complete recovery ensued One patient sustained wedge-compression fractures of the fourth fifth and sixth cervical vertebrae.

Five of the fractures were reduced by traction. In these reduction was almost complete In 2 instances restoration of shape of the deformed vertebra was satisfactory Stabilization of the spine by fusion was effected in 2 of the 6 patients All of the patients returned to work—in 4 patients *in 5½ months One with multiple major* injuries resumed work in 24 months and one with cord injury in 14 months

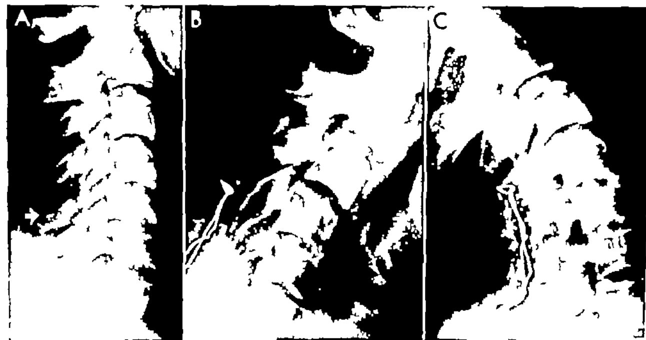


Fig 143 —A, wedge-compression fracture of the fifth cervical vertebral body shortly after injury No cord damage B result at the end of 8 years Flexion C extension. Bone fusion was solid the patient had resumed work as a printer 6 weeks after the injury He had remained *symptom-free since* operation (Reproduced from Journal of Bone and Joint Surgery 1957)

Bursting Fractures of the First Cervical Vertebra (Jefferson s Fracture)

As with the bursting fracture of a vertebral body in the lumbar region bursting fracture of the first cervical vertebra results from violent compression in the long axis *of the spine Usually the patient is thrown* or falls from a height in such a way that



Fig 144 —Anteroposterior (A) and lateral (B) views of a bursting fracture of the atlas (The fracture occurred when the horse which the patient was riding in a steeplechase refused a jump and the patient was thrown over the fence landing on top of his head and bursting the atlas There were no cord symptoms) Notable is the fracture through the groove of the vertebral artery in the lateral view also the fracture through the right lateral mass including the attachment of the anterior arch of the atlas to the right lateral mass of that bone in the anteroposterior view C the reduction obtained by skull traction D and E, result 12 years after the accident. Patient was symptom free (Reproduced from Journal of Bone and Joint Surgery 1957)

he lands on the top of his head The condyles of the occiput which are directed distally and laterally are forced against the superior articulations of the atlas and acting as a wedge burst the ring of bone which constitutes the atlas The resulting fracture may be single or multiple Posteriorly the fractures occur through the grooves of the vertebral arteries (Fig 144 *B*) anteriorly they may occur on either side at the junctions of the anterior arch of the atlas with the lateral masses The lateral masses of the atlas tend to become displaced laterally (Fig 144 *A*) This fracture does not appear to be a common one there were 2 cases in this series

No evidence of cord injury was present in either of the 2 fractures of this type in 1 instance complicated by a fracture-dislocation of the second upon the third cervical vertebra there was partial interruption of cord conductivity in the vicinity of the injuries not associated with the injury of the atlas Reduction was accomplished by skull traction in each of these 2 fractures and union occurred in both The patient in whom the fracture was complicated by an anterior fracture-dislocation of the second upon the third cervical vertebra (an elderly man who had retired) complained of pain after healing had taken place he had at least half of the normal range of motion Here it was necessary to stabilize the spine by wire fixation and fusion. The other patient resumed full pre-injury activities in 6 months

Bursting Fracture of the Vertebral Body

A bursting fracture results from violent compression of the vertebral body between the body of the vertebra above and the body of the vertebra below Commonly the injury occurs during diving into shallow water The force is applied directly in line with the long axis of the spine As in lumbar bursting fractures the nucleus pulposus of the disk above and that of the disk below are forced into the core of the body causing it to burst. But unlike some bursting fractures of lumbar vertebrae in fractures of the cervical vertebrae the cervical body breaks into several large fragments (Fig 133 *A*) The centrum, as seen in the lateral roentgenogram, appears to have been split into one or more anterior fragments and one or more posterior fragments The sharp anteroinferior lip of the centrum above appears to have been driven into the fractured vertebral body splitting it in the coronal plane The anterior fragments appear to have tipped backward superiorly and to have become displaced forward inferiorly The main posterior fragment is tipped forward superiorly and displaced backward inferiorly

More important is the dangerous backward displacement of the main posterior fragments into the vertebral canal which may cause cord compression by decreasing the anteroposterior diameter of the vertebral canal Lateral displacements may cause nerve-root compression.

As seen in the anteroposterior roentgenogram the vertebral body appears to have been split vertically in the sagittal plane (Fig 133 *B*) In the inferior portion of the vertebral body there may be little or no lateral displacement of fragments Presumably the upward lateral projections of the vertebra below prevent this Superiorly however there may be slight but definite lateral displacement of fragments for the lateral processes of the fractured vertebral body do not clasp the vertebral body above but are spread apart Each lies lateral to the normal position

In view of this skeletal displacement, neurological symptoms are to be expected and actually they do occur frequently The bursting fracture of a cervical vertebra is an especially dangerous injury as it is in other regions of the vertebral column In this series there were 12 injuries (14 per cent) in 10 patients only 2 of whom escaped neurological changes Two patients experienced immediate complete interruption of cord function One improved only slightly in the 7 weeks before he died of a massive pulmonary infarction the other improved early in neurological status and was nearly

normal 8 months afterward In 3 patients there was immediate partial interruption of cord function 2 of these improved to nearly normal and 1 was normal Three others had immediate symptoms of nerve root compression all improved subsequently to normal

Skull traction produced nearly complete reduction in each of the 7 patients on whom it was used all had fresh fractures (Fig 133 C) Halter traction maintained a satis factory position of fragments in 1 patient and plaster-of paris fixation in another One patient with a minor deformity received no treatment his fracture healed without in cident.

Internal fixation and surgical fusion re-sulted in stable cervical spines in all 8 pa tients on whom operation was performed In none of these patients did cord symptoms persist or recur One quadriplegic patient died of pulmonary infarction in 7 weeks In one patient the fracture healed without treatment. Of the 10 patients in this group 9 resumed preinjury activities in 5 months

Unilateral Rotatory Dislocation

Unilateral rotatory dislocation is caused by forcible lateral flexion and rotation of the cervical spine away from the disloca tion as the result either of muscle action or of indirect violence (Fig 134) The dis-location may also occur spontaneously in the rheumatoid cervical spine and during sleep in children with upper respiratory tract infections Such spontaneous disloca tions appear to follow abnormal relaxation of the binding ligaments

There were 9 unilateral rotatory disloca tions in 8 patients in this series In only 2 patients did symptoms of cord damage de velop as a result of the injury These symp-toms indicative of partial interruption of cord function appeared in a patient who was struck on the head by a heavy plank and knocked down They came on immedi ately after the injury and began to dis appear in a few minutes Motor power returned in 15 minutes The second patient was thrown through the windshield of an automobile He immediately became quadriplegic and remained so

With this type of injury traction failed to reduce the dislocation in each of the 5 patients on whom it was employed In 1 patient skull traction partially reduced the dislocation between the atlas and the sec ond cervical vertebra

Six of the 8 patients in this group were operated on Open manipulative reduction was successfully performed and a fusion operation was carried out in 3 patients The dislocated vertebra in each of the other 3 patients was fixed by a wire loop and suc cessfully fused to the vertebra below Fixa tion and fusion in the latter 3 patients was performed without reduction because the superior articular process of the vertebra below had been fractured and could not therefore be relied on to prevent recurrence of the dislocation and to immobilize the spine in the vicinity of the injury There was no recurrence in the 3 patients in whom the dislocation was reduced In 4 of the 6 patients operated on fusion was ob-tained. Another an elderly patient with marked marginal lipping died of cord dam age during laryngoscopic tracheal intuba tion (intranasal intubation has been em ployed in all subsequent cervical spine operations) There was one apparent fail ure of fusion

Six of the 8 patients in this group re-sumed preinjury activities in an average of 5 months

Anterior Dislocation

In the cervical spine anterior dislocation without fracture of the body of the vertebra below occurs chiefly as a result of shearing forces which violently displace one vertebra forward upon another commonly the pa tient falls landing on the back of the head The ligaments which bind the vertebrae together posteriorly are notably weak. At operation they are found to have been ex tensively ruptured Unless muscles act to maintain stability the dislocating vertebra no longer held by the posterior ligaments is

then displaced anteriorly carrying with it the vertebrae above

If the superior articular processes of the vertebra next below the dislocating vertebra do not fracture as a result of the violence the posterior elements of the dislocating vertebra are tipped forward and upward by the inclination of the articular facets The displacement may result in partial or complete dislocation depending on the magnitude of the violence and the resistance of the column to it. When the inferior articular processes of the dislocated vertebra lie anterior to the superior articular processes of the next vertebra below the dislocation is complete (Fig. 129 A) When they are still posterior but displaced upward and forward the dislocation is partial (Fig. 145 A)

In the thoracic spine anterior dislocation may occur with complete rupture of the disk and of the binding ligaments the cord may be transected and reduction may then take place spontaneously It seems probable that similar spontaneous reduction may occur in the cervical spine (Fig. 139)

There were 31 anterior dislocations without fracture of the vertebral body in 29 patients In 12 of the 29 patients the symptoms of complete or partial interruption of cord function were present immediately following the injury and in 4 patients cord interruption occurred subsequent to the injury but before definitive treatment could be established Seven patients died as a result of complete interruption of cord function (Tables 9 and 10)

Reduction of the dislocation was effected by traction or maintained by it in 22 of the 29 patients on whom it was employed—16

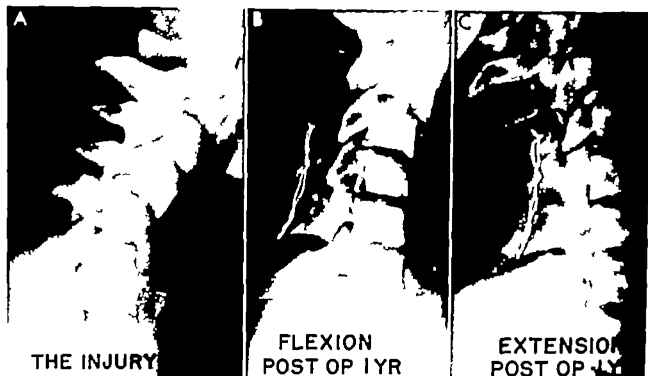


Fig 145 —A, partial dislocation anteriorly of the fifth upon the sixth cervical vertebra. The articular processes are still engaged, the dislocating forces having become spent before the displacement was complete There had been partial loss of cord function immediately after the accident. Neurologically recovery began very soon afterward and was complete in a few days Reduction was effected at open operation 4 months later The vertebrae were fixed with wire and bone grafts were applied. Fusion was solid in 8 weeks B appearance 1 year later Flexion. C extension Patient had been regularly at work as a deep-sea fisherman for 8 months (Reproduced from Journal of Bone and Joint Surgery 1957)

by skull traction and 6 by halter traction Open reduction was performed in 3 patients in each of whom the reduction was complete Following reduction the dislocated vertebra was fixed to the vertebra below with wire and bone grafts were applied in 15 patients In another patient an irreducible dislocation was fused with minor displacement In each of these 16 patients solid bone fusion was obtained 13 of them returned to work the average time of return being 5 months

Recurrence of the dislocation following reduction and prolonged external fixation occurred in 2 patients in these series In neither was internal fixation and fusion done following reduction in both spontaneous (*interbody*) *fusion* occurred in 8 and 9 months respectively

Anterior Fracture Dislocation

Anterior fracture-dislocation of cervical vertebral bodies is caused by forces similar to those which produce the anterior dislocation without fracture with the notable exception that considerable longitudinal compression is present. As a result a wedge-compression fracture is produced in the subjacent vertebra in addition to the forward displacement of the dislocated vertebra. If the injuring forces are then not spent one or both pedicles of the dislocated vertebra may fracture provided that the posterior articulations hold (Fig 146 *A*) In 8 patients there were 9 anterior fracture dislocations Pedicle fracture occurred in 2 of these patients

Symptoms of interruption of cord func



Fig 146 —A an anterior dislocation of the second upon the third cervical vertebra together with a wedge-compression fracture of the body of the third vertebra. The pedicles of the second vertebra were fractured No dislocation of the posterior articulations between these two vertebrae No evidence of interruption of cord conductivity B reduction was effected by traction The first, second, and third vertebrae were wired together and bone grafts were applied posteriorly across the vertebral arches of these three segments C roentgenogram made 6 months after the operation showing maintenance of the reduction and bone fusion. There were no symptoms patient had been at work for 3 months (Reproduced from Journal of Bone and Joint Surgery 1957)

tion were present in 3 of these 8 patients 2 had *complete interruption* and 1 had partial interruption (Tables 9 and 10)

Reduction of the fracture-dislocation was effected by *traction* in 4 of the 8 patients Open reduction was done in 1 patient. In the 2 patients in whom traction failed to effect a reduction, the injury had occurred 2 and 4 months prior to treatment

of the ossified longitudinal ligament of the cervical spine may occur between two vertebral bodies Angulation at the fracture site may be forward or backward depending on the direction of the fracturing forces

One patient who had sustained this injury (Fig 147) *had fallen face down* striking his forehead. There were no *symptoms* referable to the cord and no root symptoms.

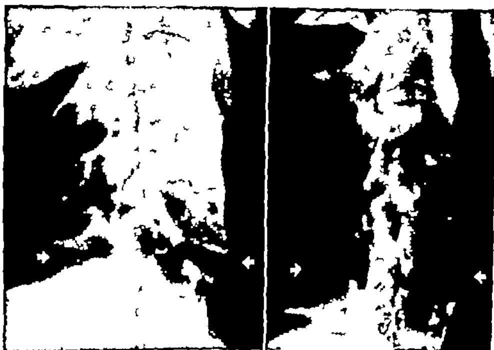


Fig. 147 —Left an extension fracture of the ankylosed cervical spine through the level of the fourth intervertebral disk. Despite complete ankylosis of the spine in flexion, the patient had managed to earn his living as a truck driver Shortly before admission he had fallen from his truck, striking his forehead on the tailboard There were no neurological symptoms. The extended position was maintained by skull traction with some improvement in his posture Right refusion took place spontaneously in the improved position in 10 weeks and patient resumed work *10 months after the injury* (Reproduced from Journal of Bone and Joint Surgery 1957)

Internal fixation and fusion were employed in 5 patients In each of these solid bone fusion was achieved and in none was there recurrence Four of the 5 patients in whom fusion was done resumed work in an average of 4 months Spontaneous fusion occurred in 2 patients. These 2 patients returned to work in an average of 8 months

Fracture of the Ankylosed Cervical Spine

When a patient with rheumatoid ankylosis of the cervical spine falls striking his head against an unyielding object fracture

Correction of the pre-existing flexion deformity was easily effected by skull traction Refusion occurred spontaneously in 8–10 weeks in a much improved position The patient returned to work 10 months after the injury

A comparable case was recorded in 1933 *and 4 other cases in 1949*

Posterior Dislocation

Posterior dislocation is the result of a shearing *force applied to the face as in a* fall forward head first displacing one vertebra backward upon another A. R Taylor

demonstrated the clinical aspects of this injury in severe form and reported autopsy findings The anterior longitudinal liga ment is ruptured at the intervertebral disk immediately below the dislocating vertebra This disk is completely torn transversely In turn the flaval and interspinal ligaments rupture and the vertebra is dislodged back ward drawing with it the intact posterior longitudinal ligament. Marked narrowing of the vertebral canal results and the cord may be crushed Spontaneous reduction of the dislocation had occurred in Taylor s patient the roentgenograms were negative although there was a complete transverse lesion of the cord In the series here re ported there were 2 patients with posterior dislocations It is unfortunate that all of the roentgenograms of one of the cases have been lost also all those of the second case except the 6-year follow up films The lat eral view of the cervical spine in the second case is shown in Figure 148 slight posterior displacement of the third upon the fourth vertebra remains Both patients had imme diate symptoms of cord injury

One patient had dived about 14 feet into deep water but had struck his head against a submerged object. There was immediate loss of consciousness and complete inter ruption of cord function Reduction by skull traction was almost complete He never re-gained cord function and died 7 months later of urinary tract infection The other patient fell from a ladder about 8 feet. From the resulting abrasions and contu sions of the face it was evident that he must have landed on his face There was immedi ate complete loss of cord function Reduc tion was effected by halter traction and maintained by skull traction There was early return of cord function which slowly continued until restoration was complete Interbody fusion was spontaneous The pa tient was observed over a period of 6 years following the injury

Hyperextension Injuries

Reference has been made earlier to the work of A. R. Taylor in which the role of extension of the cervical spine in cord injury was demonstrated As a result of hyperextension the flaval ligaments are compressed which causes them to bulge forward This may result in cord compres sion especially if there is narrowing of the canal due to marginal lipping anteriorly along the posterior borders of the vertebral



Fig. 148 —Lateral view of a healed pos-terior dislocation of the third on the fourth vertebra which had been almost completely reduced 6 years before Interbody fusion oc curred between the second and third fourth and fifth and fifth and sixth vertebrae Pa tient had recovered almost to normal following quadriplegia. (Reproduced from Journal of Bone and Joint Surgery 1957)

body Such lipping is present in many elderly people There were 2 such cases in this series Both patients became quadri plegic through hyperextension and both died as a result. In each hyperextension injury occurred during the course of treat ment of the dislocation. Both patients were old and had advanced marginal lipping In each case permission for necropsy was denied

One of the patients aged 64 was admit ted with a complete anterior dislocation of the fifth upon the sixth cervical vertebra

He had fallen downstairs 1 week before striking the back of his neck. There were mild symptoms of nerve-root pressure bi laterally in the distribution of the sixth and seventh cervical nerves There was advanced marginal lipping (Fig 138) Halter traction was applied. Soon afterward, the patient was reported to have become very restless tossing about in bed. When re examined an hour after the application of the halter traction he was found to have become quadriplegic from the fifth cervical level downward. There was a partial block of the cerebrospinal fluid X ray films showed reduction with hyperextension of the fifth upon the sixth vertebra.

The other patient a woman aged 62 was admitted with a unilateral rotatory dis location of the fifth upon the sixth vertebra she had fallen downstairs an hour before. There was advanced marginal lipping Hal ter traction was applied without effecting a reduction and after 8 days skull traction was applied for 6 days without success She was then operated on, open reduction being easily effected with the neck under skull traction During tracheal intubation with the aid of the laryngoscope for endotracheal anesthesia the patient s neck was accidentally hyperextended. When she recovered from the anesthesia she was found to be quadriplegic from the fifth cervical level.

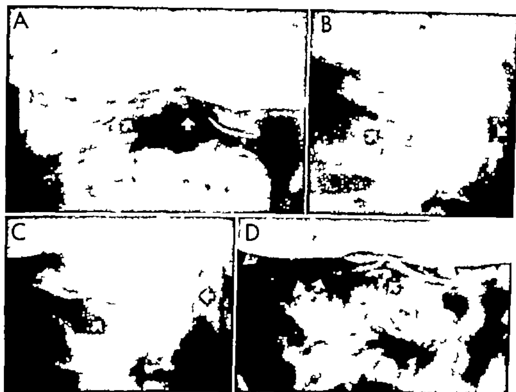


Fig 149 —Anteroposterior (A) and lateral (B) views of a fracture of the odontoid process. Posterior dislocation of the atlas upon the axis odontoid process was displaced backward with the atlas C reduction was obtained by skull traction and was almost complete D although union of the fracture of the posterior arch had occurred within 3 months of the time of injury nonunion of the odontoid fracture was still present at follow-up examination 5 years later Patient was symptom-free normally active and had a normal range of cervical motion The dislocation had not recurred The examination was negative neurologically (Reproduced from Journal of Bone and Joint Surgery 1957)

Because of the hazard of hyperextension injuries laryngoscopic tracheal intubation is contraindicated in surgery of the cervical spine

Skull traction is indicated in cervical injuries in elderly people especially in the

presence of hypertrophic arthritis with marginal lipping of the vertebral bodies posteriorly

Halter traction is contraindicated in all cervical spine injuries except those in children If at all effective it causes discomfort in adults because of undue pressure on bony prominences such as chin and occiput It leads to restlessness and tossing about in bed which are always dangerous in these injuries and may be fatal

Posterior Fracture Dislocation

Posterior fracture-dislocation is caused by forcible hyperextension. A backward displacing force is combined with compression in the long axis of the spine to drive one vertebra backward and downward upon another next below fracturing the latter and dislocating the former posteriorly A fall downstairs head foremost the victim landing on the face is the usual type of accident Cord damage may occur (Fig 137 *A*)

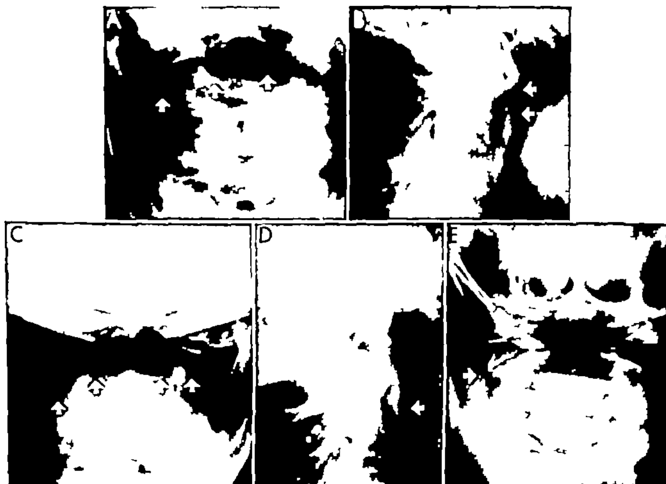


Fig 150 —Anteroposterior (A) and lateral (B) views of a fracture at the base of the odontoid process and a crush fracture of the right superior articular process of the second cervical vertebra. C and D only partial correction of the deformity was obtained by skull traction E, the result 3 years after injury There is evidence of traumatic arthritis of the right lateral articulation between the axis and the atlas and depression of the right articular process of the axis Patient was symptom-free (Reproduced from Journal of Bone and Joint Surgery 1957)

There were 2 patients with this injury in this series While posterior fracture-dislocations may involve lower cervical vertebrae both patients with this injury sustained it in the first and second vertebrae In 1 patient the vertebral arch of the atlas was fractured evidently by compression against

the arch of the second cervical vertebra In both the odontoid process was fractured. The odontoid process and the atlas were displaced together posteriorly Skull traction effected reduction in one and maintained the reduction secured through halter

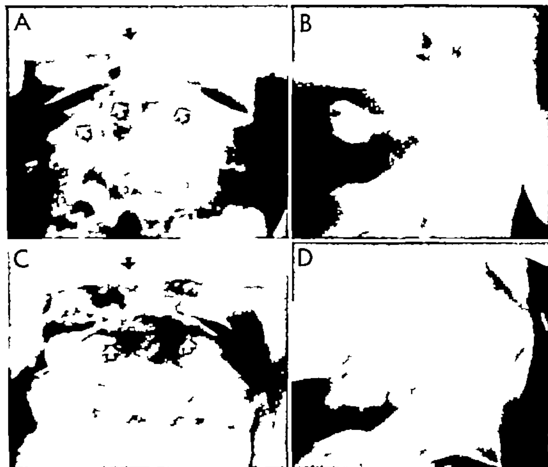


Fig 151 —Anteroposterior (A) and lateral (B) views of a fracture of the odontoid process. Moderate displacement, the process being inclined to the right and a compression fracture of the right superior articular process of the axis Union of the fracture occurred with traumatic changes in the right superior articular process of the second vertebra, 3½ months after the injury C and D roentgenograms made at follow-up examination 12 years after injury (Reproduced from Journal of Bone and Joint Surgery 1957)

traction in the other Union of the fracture of the odontoid process occurred in approximately 4 months in 1 patient. Non union of the odontoid process developed in the other (Fig 149 *D*) although the fractures of the vertebral arch of the atlas united within 3 months of the time of injury Internal fixation and fusion were not done These patients were observed for 5 and 7 years respectively In neither was there recurrence of the dislocation

In 1 of these patients there had immediately been almost complete loss of cord function in the close vicinity of the injury From this loss of function there was considerable recovery (she could care for her self) although she never regained economic independence There never was any neurological damage in the other patient.

Fracture of the Odontoid Process

When fracture of the odontoid process occurs without dislocation of the atlas the fracturing forces seem to be complex. Blockey and Purser have studied the mechanism of fracture of the odontoid process in

a series of 46 adults They feel that any force which violently flexes extends or rotates the head on the neck may avulse the odontoid process In the Massachusetts General Hospital series the x ray appearance of the injured second vertebra suggests that the injuring mechanism in 3 of the 5 patients with this injury was forcible flexion and rotation In each of these patients there appeared to be a crushing of the superior articular process of the second vertebra on one side in addition to the typical odontoid fracture described by Blockey and Purser (Figs 150 151 *A* and 152 *A*) In 2 of the 5 patients in this category there had occurred a fracture of the odontoid process without displacement or crushing of either superior articular process.

In only 1 of the 5 patients were there neurological symptoms either of cord or nerve root origin This patient complained of unilateral occipital pain which proved to be temporary

In 1 of these patients with lateral crushing reduction was effected by skull traction. Halter traction failed to correct the deformity in the other 2 patients

Nonunion occurred in 1 patient in the group her injury consisted of a fracture of the odontoid without displacement and without crushing of either superior articular process She had been treated by halter traction and a cervical brace At last follow up examination 7 years after the injury she stated she had been symptom free for a number of years

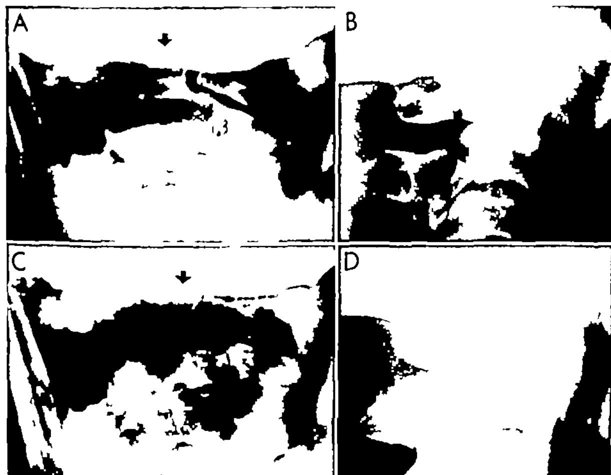


Fig 152.—Anteroposterior (A) and lateral (B) views of a fracture of the odontoid process Moderate displacement the process being inclined to the left and a compression fracture of the left superior articular process of the axis C and D union of the fracture occurred with traumatic changes in the left superior articular process of the axis 4 months after injury The x ray films were made at follow up examination at 9 years (Reproduced from Journal of Bone and Joint Surgery 1957)

All 5 patients returned to work in an average of 8 months

Fracture of the Odontoid Process with Anterior Dislocation of the Atlas

Fracture of the odontoid process with anterior dislocation of the atlas apparently results from a violent shearing force directed anteriorly The ligaments which bind the lateral articulations of the atlas to the second vertebra rupture and the atlas is displaced forward on the axis carrying with it the odontoid process which fractures across its base Should the odontoid process not fracture the inevitable result must be death from high cord transection Kahn and Yglesias have shown that if the dislocation is not reduced there is a tendency for the displacement to progress until finally symptoms of cord compression appear These neurological symptoms may be of insidious and slowly progressive onset or they may abruptly develop into quadriplegia.

There were 2 patients with this type of injury in this series One had had the condition for 7 months (Fig 141 *A* and *B*) there were no neurological symptoms The other patient had had the condition for 19 years during which time he had had four episodes of quadriplegia from each of which he had recovered

Complete reduction of the fracture-dislocation was obtained in 1 of these patients by skull traction (Fig 141 *C*) The atlas was then wired and fused to the axis He made an uneventful recovery He returned to work in 7 months and at follow up 5 years later had worked steadily without any untoward symptoms In the other patient the occiput was fused to the second vertebra, laminectomy of the atlas having been performed Following this operation the patient was almost completely quadriplegic Later he regained cord function to a point which represented neurological improvement over his preoperative condition He never regained his capacity to work

Summary of Fractures of the Odontoid Process (in Adults)

There were 9 fractures of the odontoid process in this series Five occurred without dislocation of the atlas upon the axis 4 occurred with dislocation of the atlas 2 anteriorly and 2 posteriorly

When displacement of axis fragments was present or there was dislocation of the atlas skull traction alone was successful in effecting reduction Wire internal fixation and fusion seems indicated in the presence of old irreducible dislocation old dislocation following reduction and atlantoaxial instability

Nonunion of the odontoid process developed in 4 of the 9 patients Failure occurred despite there being no displacement of the odontoid process in 2 patients One had been treated by halter traction and brace fixation the other had been recumbent under skull traction for 10 weeks Neither patient had any untoward symptoms as a result both resumed work. These patients were under observation for 5 and 7 years following injury one first reporting for treatment with established nonunion. The other 2 instances of nonunion developed in patients who had received no treatment for their anterior fracture-dislocations One had been injured 19 years before the other 7 months before Both spines were fused both united posteriorly but in each the odontoid failed to unite even after the surgical fusion

Essential Points

The following factors are important in the treatment of fractures and dislocations of the spine

1 For the dangerous period between the time of injury and definitive treatment and while the patient is being moved about during definitive treatment he should at all times be recumbent on a firm stretcher or bed An adjustable traction neck brace should be worn during these times applied

in the long axis of the spine in the neutral position

2. Skull traction is the best proved means of protecting the cord during definitive treatment of cervical spine injuries

3 Skull traction will accomplish reduction and maintain it in a high proportion of injuries It is comfortable and greatly facilitates nursing care

4 Complete reduction is ideal However reductions may be satisfactory in those patients in whom there is less than 0 3 cm. decrease in the anteroposterior diameter of the vertebral canal Open reduction has been accomplished in patients in whom skull traction has failed

5 Internal fixation and surgical fusion provide reliable stabilization of the injured vertebrae These procedures appear to protect the cord against attrition in patients with a vertebral canal of less than normal diameter

6 The treatment of cervical spine injuries is highly specialized technical errors in treatment may be fatal. A trained and experienced operating team is essential.

THE THORACIC SPINE (UPPER TEN THORACIC VERTEBRAE)

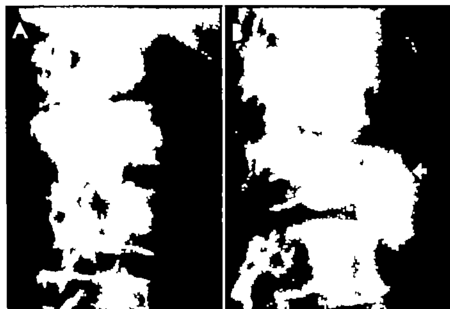
In the upper ten thoracic vertebrae fractures and fracture-dislocations are uncommon Stability characterizes this segment of the spine with its narrow intervertebral disks and relatively flat vertebral end plates As a result, the thoracic spine is comparatively rigid and compression flexion forces are transmitted to the more mobile less stable lumbar or cervical segments where these injuries are far more prone to occur

Wedge-Compression Fracture

When the spine is the seat of senile or postmenopausal osteoporosis wedge-compression fractures are not uncommon in the thoracic spine They may then occur singly or be multiple or they may be found in association with the same type of fracture in the lumbar region Biconcave vertebrae may also be found in both of these segments in the osteoporotic spine owing to the vertical compression of the soft bone by the nucleus pulposus above and below These fractures may be overlooked because they result from such minor traumas as a moderate lift when the spine is in the forward bent position or from suddenly rising from a chair or bed or from sitting down heavily Rest in bed (for several days to several weeks) will usually suffice to relieve the pain and restore these patients to limited activities The fractures should not be reduced and the vertebrae should not be fixed in plaster-of-paris jackets The support will only cause further bone atrophy

Uncommonly a thoracic vertebra (upper ten) of normal density becomes compressed into a wedge shape Correction of such fractures and fixation in extension with the plaster-of paris jacket so important in the lumbar spine are usually unnecessary when the fracture is in the thoracic spine The reason for this lies in the innate stability of this segment of the vertebral column Patients become symptom free and resume preinjury activities after a shorter period of disability without reduction and jacket fixation than with these methods which are so successful in lumbar region fractures Rest in bed until the patient is free of pain (several days to several weeks) early active exercises to develop the spinal extensors and a gradual resumption of activities will yield consistently good results

Adolescent Epiphysitis —The wedge shaped deformities seen in the lateral roentgenograms of thoracic vertebrae resulting from active or healed adolescent epiphysitis (Scheuermann s disease) are not to be mistaken for wedge-compression fractures They may be distinguished by the presence of characteristic hernial protrusions of disk tissue into the involved centra by the absence of convexity of the anterior walls of these bodies and in individuals usually over 35 years of age by proliferative bone changes along the margins of the disks



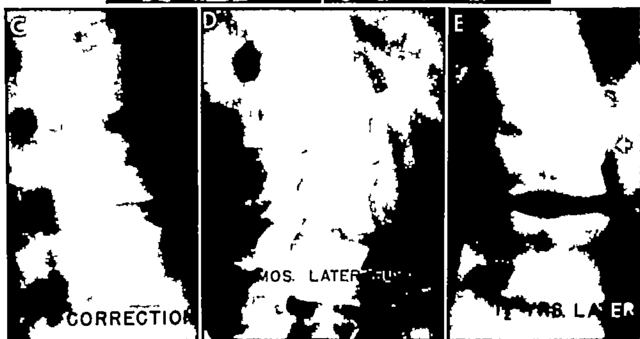


Fig 153 —A, the common wedge-compression fracture with apex of the wedge pointing anterolaterally B with apex of wedge directed forward—the usual case C correction of the anterior crushing. D lateral crushing persists bone bridging complete 6 months later E lateral view 1½ years after injury (Reproduced from W A Rogers Arch Surg 30:284 1935)

Fracture Dislocation

Fracture-dislocation in the thoracic region is not common, for the same reason that wedge-compression fracture is not common—the high degree of stability of the thoracic spine (p 245 Fig 161) Great violence is necessary to produce this injury and the spinal cord may be irreparably damaged when the condition is found Open reduction with or without laminectomy followed by spine fusion should be done early

THE LUMBAR SPINE (INCLUDING THE 11th AND 12th THORACIC VERTEBRAE)

The two common fractures of the lumbar spine are the wedge-compression frac

ture of the vertebral body and the fracture of the transverse processes Less common is the bursting fracture of the vertebral body The fracture-dislocation is uncommon As separate entities fractures of the articular and spinous processes of the laminae and of the pedicles are almost rarities The hyperextension vertebral body fracture is rare as compared to the flexion type end plate of the compressed vertebra is usually fragmented and there is tearing of the fibers of the annulus fibrosus Through the rents in the annulus the nucleus pulposus of the damaged disk is forced along the fracture fissures into the core of the centrum These changes result in replacement of the disk by scar tissue with loss of the normal disk mechanics and there results a

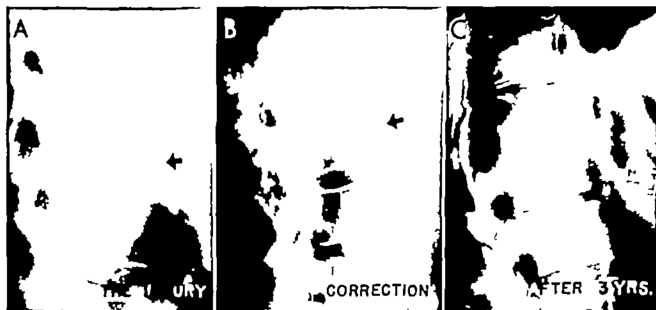


Fig 154 —A wedge-compression fracture of first lumbar vertebra Slight anterior dislocation, but posterior wall of the centrum is intact. B hyperextension of the spine while under traction has restored the shape of the crushed vertebra almost to normal. C the fractured vertebra 3 years later No loss of bone correction The intervertebral spacing is decreased

Wedge-Compression Fracture of the Vertebral Body

Forcible hyperflexion of the lumbar region of the spine results in compression of the vertebral body into a wedge shape The apex of the wedge is usually directed forward less frequently it points laterally (Figs 153 and 154)

It is usually the anterosuperior portion of the centrum which is compressed Uncommonly the anteroinferior portion is involved. Since most of the vertebral body is composed of cancellous bone much of the compression takes place through meshing of the trabeculae Incident to the compression, there is considerable obliteration of blood sinuses which results in more or less avascular necrosis The superior articular

decrease in the intervertebral spacing Such changes were noted in 26 of a series of 31 patients at the Massachusetts General Hospital (Figs 132 and 154) The later changes are degenerative with marginal lipping subchondral bone sclerosis and spontaneous intervertebral fusion

In the wedge-compression fractures there is no element of dislocation of the vertebra as a whole the vertebral canal is not decreased in diameter and the posterior wall of the centrum remains intact The interspinal and flaval ligaments attached to the posterior bone structures may be mildly sprained If there is evidence of severe soft part injury posteriorly one must at once suspect dislocation.

Compression fractures are common in postmenopausal and senile osteoporosis

Diagnosis

THE HISTORY —Great violence is not necessary to produce this fracture The usual history is of a fall the patient land ing on the feet buttocks or shoulders of an automobile accident or of a heavy ob ject falling on the shoulders The spine is hyperflexed anteriorly or laterally

PAIN —In the thoracolumbar or lumbar region pain and tenderness may be pres ent localized in the region of and deep to the spinous processes of the involved ver tebra.

X RAY EXAMINATION —Painstaking ex amination with the aid of the x ray is indispensable The usual lateral and antero-posterior exposures should be made If there is any doubt the x rays should be directed obliquely through the posterior articula tions on both sides Vertebral dislocation must always be excluded If one or more of the vertebral bodies are compressed into a wedge shape the posterior wall of each of the involved centra should be carefully checked in the lateral roentgenogram for any evidence of fracture The presence or absence of fracture fissures or compression (as in bursting fractures) or dislocation will thereby be determined beyond a doubt (Figs. 130 and 131)

Treatment

WITHOUT REDUCTION — Mild wedge-compression fractures in which no element of dislocation and no fracture involving the posterior wall of the centrum has been dem onstrated may be treated without reduction as a ligamentous injury This method has been strongly advocated by Nicoll and it appears to have met with some success in Britain and on the Continent in more severe fractures of the vertebral bodies The pa tient should be confined to bed for 2–3 weeks but without other early immobiliza tion After a few days as the pain subsides active exercises may be begun which de velop the erectores spinae to a point where presumably they may compensate for the angulation of the spine at the site of frac ture Later as the patient becomes ambula tory a belt corset or back brace may be worn

The results of treatment by this method in the Massachusetts General Hospital ap pear to be satisfactory provided that the degree of wedge deformity is slight (the amount of compression has been arbitrarily set at less than one fourth of the vertical diameter of the vertebral body at the ante rior wall) and that the patient does not lead an athletic or physically laborious life

WITH REDUCTION — THE HYPEREXTEN SION JACKET —Since hyperflexion and com pression forces produce the fracture and the deformity restoration of the shape of the vertebrae may be expected by reversing these forces Actually extension and trac tion may restore the wedge-compression centrum almost to its preinjury form (Fig 153) During extension and traction the anterior longitudinal ligament gradually tightens Through Sharpey s fibers this ligament gains attachment not only to the cortex of the vertebral body anteriorly and laterally but to cancellous elements deep within Thus as the ligament becomes taut at the normal limit of extension the com pressed fragments of bone are decom pressed and pulled back into almost normal position the shape of the body being almost completely restored Reductions carried out to the absolute limit of normal extension may be relied on to restore the shape of the compressed vertebra to such an extent that gross angulation of the spine at the level of the fracture is avoided Often compressed vertebral bodies may be restored practically to normal. Extension of the spine to less than the absolute limit will fail to result in a satisfactory reduction.

Posteriorly tears may have occurred in the supraspinal interspinal and flaval liga ments as a result of the injury These liga ments will be in an ideal position for healing since in extreme extension torn ends will be firmly opposed

Anesthesia —A general anesthetic is un necessary for the reduction Actually it is contraindicated on the ground that it de prives the surgeon of assurance concerning

the condition of the cord and nerve roots during reduction Morphine in two doses of 12 mg each and at the same time 25 mg of scopolamine given together hypodermically 1 and 2 hours before reduction should allay the patient s apprehension and produce sufficient relaxation

METHODS OF REDUCTION —Among the several efficient methods of slowly placing the lumbar spine in absolute hyperextension, the traction-extension method the Goldthwait irons method (p 240 Fig 156) and the two-table method are preferable

Traction Extension Method —This method has the advantage of being fully under control, and it facilitates the application of an efficient plaster-of paris body jacket Reduction by this method is without discomfort, and the surgeon s control of the spine is complete at all times

The patient is placed in the prone position on a strip of 8-inch duck webbing drawn taut lengthwise on a rectangular frame Anklets with straps are laced to both ankles over sheet wadding and fastened to a block and tackle fixed to a point at the ceiling directly above the midthighs The spine is slowly extended as the patient s lower extremities are raised by means of the pulley blocks and tackle The normal limit of extension varies considerably with the type of body build the spine usually being hypermobile in individuals of long slender physique and more limited than average in stocky patients Complete extension is never reached until the pelvis has been raised well above the webbing strip (at least 6 inches)

When extension has been continued to the normal limit the reduction will have been completed. This method has been the most satisfactory of the methods used at the Massachusetts General Hospital (see Figs. 129 and 154)

The *plaster-of paris* jacket (Fig 155) is applied at the completion of the reduction in the position of hyperextension Stockinette applied directly to the trunk before the reduction is covered with a thin layer of felt, which encircles the pelvis in order to protect the iliac crests Another thin layer of felt encircles the upper chest to protect ribs and sternum A third strip of thin felt overlies the tips of the spinous processes Over this padding the plaster-of paris bandages are snugly applied until the jacket is about 3/16 inch thick The jacket extends in front from the suprasternal notch to just distal to the anteroposterior

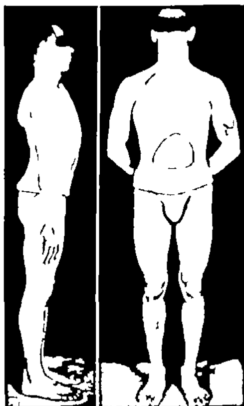


FIG 155 —Plaster-of paris jacket used to maintain correction in wedge-compression fractures of lumbar vertebral bodies (Reproduced from Rogers W A. in Scudder C L. (ed) *Treatment of Fractures* [Philadelphia W B Saunders Company 1939])

iliac spines and behind from the lower angles of the scapulae to midsacrum When the plaster has hardened the webbing is cut and withdrawn After 24 hours when the plaster has hardened sufficiently a circular window is made opposite the epigastrium This will add to comfort without loss of the effectiveness of the fixation

Other Methods of Reduction —Other methods of reduction include the Goldthwait irons and the two-table method

The *Goldthwait irons* (Fig 156) consist

of two moderately flexible bands of spring steel supported on a steel frame The bands are bent opposite the lumbar segments so that the lumbar spine will assume the posi tion of hyperextension when the patient is placed on the frame. Opposite the thoracic spine the irons either are kept straight or are slightly curved upward (for young pa

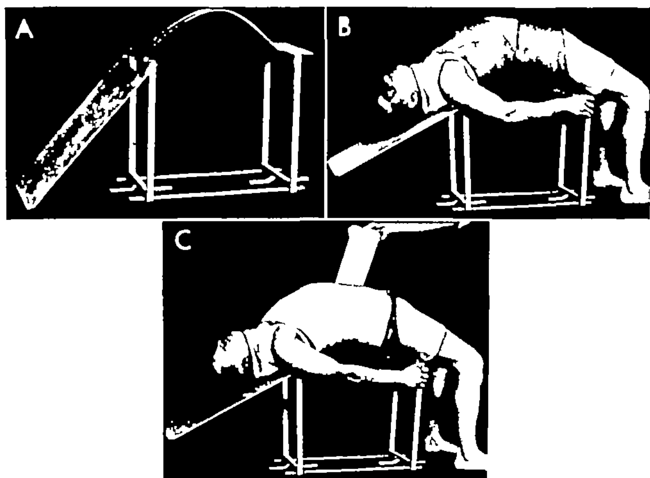


Fig 156 —A, Goldthwait irons as used in correction of lumbar wedge-compression fracture. B felt padding used in jacket fixation C application of the plaster-of paris jacket. (From Rogers W A Treatment of fractures of vertebral bodies uncomplicated by lesions of the cord Arch Surg 30 284 1935)

tients) The patient is laid supine on a thin layer of felt, on the apparatus which has been prepared as described The plaster-of paris jacket as it is applied must include the spring-steel bands on which the patient lies When the jacket has hardened suffi ciently the bands are withdrawn proxi mally after reshaping to allow their free passage between the patient and the jacket (Fig 132)

In the *two-table method* the patient is placed prone across the space between two tables The lower limbs below the level of the pelvis rest on one of the tables while the patient supports himself by the arms on the other table which is at a higher level the spine sags to the normal limit of hyper extension It is essential that neither the pelvis nor the chest rest on either table instead the tables must be placed so that the spine becomes fully extended and only the limbs rest on the tables The plaster-of paris jacket is applied with the spine in complete extension.

For many years the two-table method has proved the most satisfactory for healthy young adults in the experience of Watson Jones

Exercises

Exercises of the erectores spinae abdominal muscles and hip extensors are started within a day or two and continued regularly throughout the period of plaster fixation. Ordinary activities should be resumed within a week or two but heavy lifting and long automobile rides should be avoided

In the erect attitude the superincumbent weight is borne by the intact posterior wall of the fractured centrum and by the apophysial joints which in extension are locked As long as the jacket holds the spine in the position of extension the fractured



Fig. 157 —A wedge-compression fracture of the first lumbar vertebra B traction-extension of the spine has restored the deformed vertebra to almost preinjury shape C fractured vertebra 4 years later Some loss of correction the intervertebral space is decreased (Reproduced from Rogers W A. Arch. Surg. 30 284 1935)

portion of the vertebral body is under no stress and healing may progress to bone repair and replacement without recurrence of deformity The length of time that the period of protection should be continued must be determined from the extent of the disorganization of the vascular system and of the bony framework that is estimated to have occurred on the basis of the amount of compression Too early weight bearing will lead inevitably to the return of deformity since bone repair and replacement will not yet have been adequate Clinical experience has made it clear that the position of extension must be maintained for 3–6 months—or longer if comminution of bone is very extensive Three months has proved adequate for very mild deformity 4 months for moderate deformity It is probable that too early weight bearing has been responsible for more unsatisfactory results and adverse criticism of the reduction jacket fixation method than has incomplete reductions faulty application of the jacket or other defects in technique

Results

Development of the reduction jacket fixation method of treatment of vertebral body injuries was begun at the Massachusetts General Hospital in June 1928 A clinical statistical study of the results in the first 30 patients to undergo this form of treatment between 1928 and 1933 inclusive was published in 1935 The period of follow up was from 8 to 55 months with an average per patient of 29 months The findings at that time were the same as those which have been consistently obtained since in several hundred patients Of the 30 patients 26 returned to work in an average of 8 months The correction of the vertebral body deformity which was obtained at the time of reduction was maintained in 24 of the 26 patients There was some loss of the

normal intervertebral spacing in 26 of the 30 patients (Fig 157)

Fracture Dislocation

When the lumbar segment of the spine is violently hyperflexed the column is subjected to a bending force directed forward or laterally and to a compression force exerted longitudinally If an injury occurs in which the bending force almost wholly predominates that portion of the column to which the force is being applied may be driven forward onto a fixed portion until the articular processes are sheared or slip off to become dislocated posterior ligaments and muscles may sometimes rupture laminae may fracture and dislocation of the vertebra and the portion of the column above may occur Such injuries result from great violence they are encountered more often in the mining districts Usually the vertebral column is subjected to both forces longitudinal compression combining with the horizontally directed force to drive a portion of the column forward and downward onto a fixed portion If the hyperflexing forces are not spent in the production of sprain where the portion of the column that is being driven forward contacts the fixed portion fragmentation or simple wedge-compression of the uppermost fixed vertebral body will occur If then, the column is forced still further beyond the limit of hyperflexion, posterior ligaments fascia, and even the erectores spinae may rupture articular processes may tear apart and become dislocated or fractured laminae or spinous processes may fracture and the vertebral body next above may dislocate forward or laterally upon the fractured vertebral body The cord or cauda equina may be compressed between the neural arch of the dislocated vertebra and the posterosuperior lip of the vertebra below or they may be compressed by disk tissue displaced as the result of the dislocation

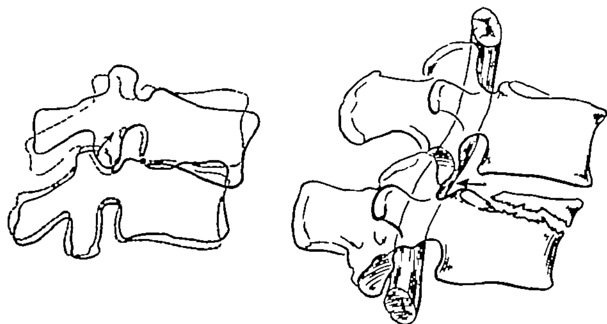


Fig 158 —Drawings showing effect of extension on the anteroposterior diameter of the vertebral canal in fracture-dislocation when the pairs of articular processes do not engage normally If the processes do not become locked to prevent further extension one or both will rotate forward into the vertebral canal as the spine is extended until finally the cord is compressed (Reproduced from Journal of Bone and Joint Surgery 1938)

Diagnosis

The History —The history of the accident is similar to that of the accidents

which produce the common wedge-compression fracture the violence is however very much greater

PAIN —In the lumbar region pain marked tenderness and swelling may be present at the level of the injury Cord or nerve-root symptoms may be present indicating complete or partial functional interruption corresponding to the vicinity of the injury or they may be absent A prompt neurological examination is essential

X-RAY EXAMINATION —At the x ray table the patient should be accompanied by a surgeon Without special handling cord or cause compression of the cord or cauda equina Manipulative extension alone to reduce dislocation should never be attempted With each increment of extension the malaligned neural arch of the dislocated vertebra will either lock more tightly with the neural arch next below or will protrude further into the neural canal and ultimately compress the cord (Fig 158) or cauda equina Open operative reduction is indicated

OPEN OPERATIVE REDUCTION — Local anesthesia is preferable in open operative reduction The patient is placed on the sur



Fig. 159 —Position on the table for open reduction of fracture-dislocation (lumbar) Left the level of the injury is directly above the axis about which the ends of the table may be lowered. Right flexion may be obtained under complete control by lowering the ends of the table

nerve root injury may occur during change of position at any time until the dislocation has been reduced

The roentgenograms should include those made by the usual anteroposterior and lateral exposures but right and left oblique exposures are also essential to show adequately the condition of the posterior articulations and of the neural arches

Reduction of Fracture Dislocation

If one vertebral body is displaced forward upon another and the dislocated inferior articular processes are out of alignment with their articulating fellows of the vertebra below spinal extension will fail to reduce the dislocation The articular processes of the two vertebrae may lock during extension blocking reduction or they may gical table in the prone position with the dislocated vertebra directly above the axis about which the ends of the table can be raised or lowered This arrangement permits flexion and extension of the spine during the operation (Fig 159)

The neural arches of the dislocated vertebra and of the vertebra next below are exposed subperiosteally and it will be found that the articular processes will have become dislocated the inferior processes of the dislocated vertebra being anterior to their articulating fellows below One or both of each pair may be fractured they may have become displaced to one side or the other and there may be over riding (Fig 160)

When the dissection of the two arches has been completed it becomes apparent that it is necessary to be able to see the dis

aligned articular processes before they can be maneuvered back into position. Reduc tion can hardly be accomplished without open operation By being able to see the dura mater the surgeon can at all times be assured that the cord is not being injured during the manipulations necessary to reduction

If there is over riding the processes may be disengaged by powerful manual traction *and countertraction* applied under the sur gical drapes by assistants This method may fail of its object however In that event the locked processes may be freed by gently *flexing* the spine accomplished under com plete control and with visual precision by *lowering* the ends of the operation table (Fig. 161 *left*) If the dislocated processes are out of line they can be pried back into line (Fig 161 *right*) Once freed and in normal alignment these processes can be made to engage their articulating fellows Once these articulating processes have been made to engage the reduction is completed by gently extending the spine This can be accomplished by raising the ends of the table until the normal limit of extension has been reached. The two spinous proc esses are then fastened together with 18- or 20-gauge stainless-steel wire and a fusion operation performed by arthrodesing the posterior articulations and packing cancel-lous bone grafts against the laminae and between the spinous processes (Fig 162)

Plaster shells are then applied.

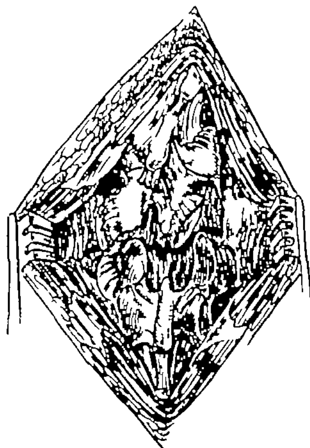


Fig 160 —Drawing of a locked and over ridden articular process as seen from behind.

Results

In 5 of 9 patients with fresh thoracic and lumbar fracture-dislocations open reduc-tion was attempted and completed in 4

patients the fusion was solid in 4 the neurological picture became normal and pre injury activities were resumed in 2 there was marked improvement neurologically and there were no back symptoms at the end result examination Two were lost to follow-up

or absent in this fracture The nucleus pulposus of the intervertebral disk above and also in more violent injuries the nucleus pulposus of the disk below are driven by the compressing force into the core of the vertebral body One or both of the articular end plates are fragmented and the vertebral

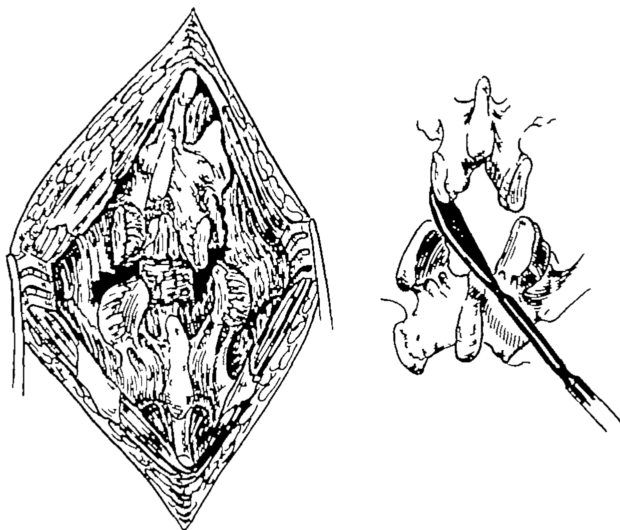


Fig 161 —By flexing the spine the articular processes are disengaged **Left** as seen by the surgeon **Right** the inferior articular processes of the dislocated vertebra are pried into normal alignment. The spine may then be extended and the reduction completed by raising the ends of the table

body is compressed. If the compression force is not then spent the walls of the centrum burst and bone fragments may be displaced outward in all directions (Fig. 163) If there is backward displacement of bone the cord or nerve roots may be compressed Fracture of the calcaneus is not uncommonly associated

Bursting Fracture of the Vertebral Body

A bursting fracture of the vertebral body in the lumbar spine is caused by longitudinal compression of the spine The horizontal force component predominant in wedge-compression fractures is negligible

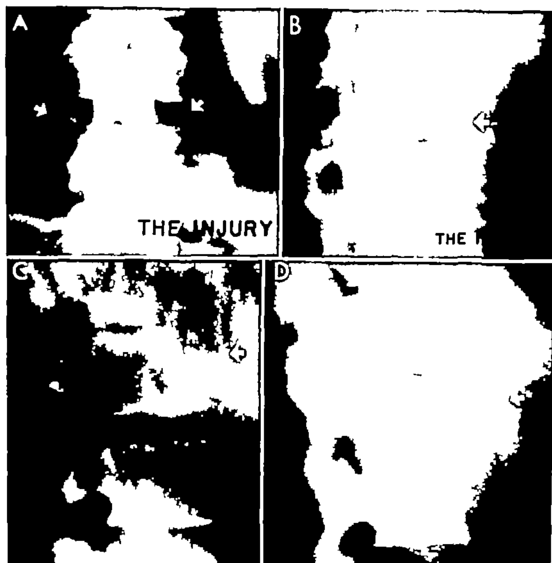


Fig 162.—Anteroposterior (A) and lateral (B) roentgenograms of the first lumbar vertebra dislocated forward upon the second At the time the films were made the articular processes were in normal alignment in the sagittal plane The anterosuperior lip of the first lumbar vertebra had been broken off and displaced forward and downward There was partial interruption of cord function immediately after the injury C showing the reduction obtained at open operation done under local anesthesia. Following the reduction bone grafts were applied to facilitate fusion D 1 year later there was no loss of reduction and bone fusion was solid Neurologically the patient had recovered almost completely and was serving in the Armed Forces as a flier (Reproduced from Journal of Bone and Joint Surgery 1938)

Neurological Examination

Neurological examinations are especially important

Treatment

When there are no symptoms of cord or nerve-root pressure and there is no very definite decrease in the anteroposterior diameter of the neural canal patients with this fracture may be treated by plaster jacket fixation Attempts at reduction have not been successful. When shattering of the centrum is extensive disruption of the blood supply and bone necrosis are inevitable Discarding the jacket should be postponed until bone repair is adequate This may require 4–6 months or longer

When there is a very definite decrease in

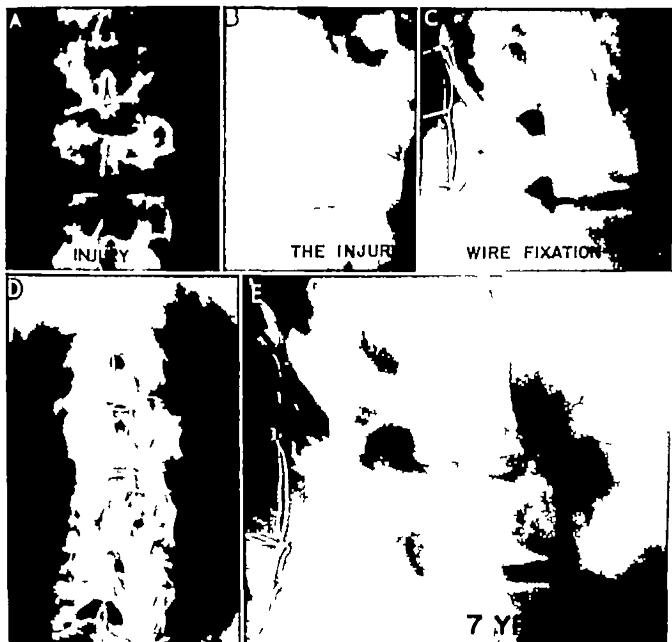


Fig 163 —Anteroposterior (A) and lateral (B) views of a bursting fracture of the third lumbar vertebra. Both articular end-plates were fractured the nucleus pulposus above and below had been driven into the core of the body there is notable decrease in height of the shattered centrum. The bone was comminuted and fragments had been forced laterally anteriorly and backward. There is a definite decrease in the anteroposterior diameter of the vertebral canal (see Fig 131 *B*) and complete paralysis of the right third lumbar nerve root C to prevent further crushing and displacement the spine was fused D and E the result 7 years later Fusion was complete No symptoms Resumption of full preinjury activities No motor paralysis but hypoesthesia in the distribution of the right third lumbar nerve root No increase in vertebral body deformity

the diameter of the vertebral canal but no symptoms of cord or nerve-root pressure spinal fusion is indicated to stabilize the spine and safeguard against late neurological changes

When symptoms of cord or root pressure are present (Fig 163) laminectomy is indicated and the spine should be fused Plaster shells followed by jacket fixation are indicated after the operation until fusion is complete

Fractures of the Transverse Processes

In fractures of the transverse processes the usual history is that of a fall a blow on the back, or a violent wrench of the trunk in an effort to maintain equilibrium as when a heavy weight born on the shoulders becomes displaced These fractures occur almost always in the lumbar spine they are uncommon in the cervical region and rare in the thoracic

Transverse process fractures are caused by violent muscular contraction of an involuntary protective nature They may occur singly and without displacement. Commonly however they are multiple (Fig 164) when they are associated with especially violent muscular contraction. If the injury is a severe one there may be considerable displacement of fragments hemorrhage hematoma and fascial and muscular tears The soft part injury may be so extensive as to prolong convalescence and leave an excessive amount of scar tissue There is a tendency to exaggeration of complaints Often however the injury is not a serious one some patients even preferring to continue their usual activities with little or no interruption.

The diagnosis is based on the history localized tenderness and aggravation of symptoms when torn structures are placed under tension It is confirmed by x ray films

It is an established fact that recovery takes place without regard to reduction of the fracture or to bone union. The surgeon should therefore direct his attention to the treatment of the soft-part injury At first this will mean protection of torn periosteum fascia, aponeurosis and muscles. How much support to provide will depend on the extent of the injury Lumbar strapping with adhesive plaster or a well fitting corset with or without a few days of recumbency will suffice in most of the milder injuries A plaster-of paris jacket may be necessary if there is much pain and muscle spasm Jackets should not, however be worn for more than 2 or 3 weeks otherwise refractory pain associated with excessive scar limitation of motion may ensue



Fig 164 —Anteroposterior roentgenogram of multiple transverse-process fractures Note the loss of outline of the psoas shadow on the left (due to a large hematoma) The psoas shadow on the right may be clearly seen The left first, second third and fourth transverse processes are fractured

As swelling subsides gentle active exercises are instituted Gradually the exercises are increased so that when soft part repair is complete (in 6–8 weeks) a normal

range of active motion may be present without pain

When the injury is of moderate severity 6–12 weeks may be required before repair is complete When the fractures are multiple and accompanied by extensive fascial and muscular rupture there may be 4 or as much as 6 months of disability

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17



Shoulder Girdle Injuries

ANATOMY AND FUNCTION

Anatomy

THE SHOULDER IS a suspended joint which functions from a movable base the scapula and from a yardarm the clavicle More specifically the shoulder girdle is composed of the following three joints (the sternoclavicular the acromioclavicular and the glenohumeral) three bones (the clavicle the scapula and the humerus) and twenty muscles The muscles are divided into three main groups extending (*a*) from the thorax to the scapula and clavicle (*b*) from the thorax to the humerus and (*c*) from the scapula to the humerus

LIGAMENTS (Fig 165) —Strong ligaments give support and stability to the sternoclavicular acromioclavicular and glenohumeral joints. Of these the most important stabilizers are the supra articular ligament of the acromioclavicular joint and the coracoclavicular ligaments (the trapezoid and the conoid)

MUSCLES (Fig 166) —The muscles of the shoulder comprise perhaps the most complex functional unit in the body There are two primary layers the musculotendinous short rotator-cuff group (the subscapularis supraspinatus infraspinatus and teres minor muscles) and the deltoid muscle The primary function of the short rotator muscles is to depress the humeral head and hold it in the glenoid fossa, thus allowing the deltoid muscle to elevate the arm.

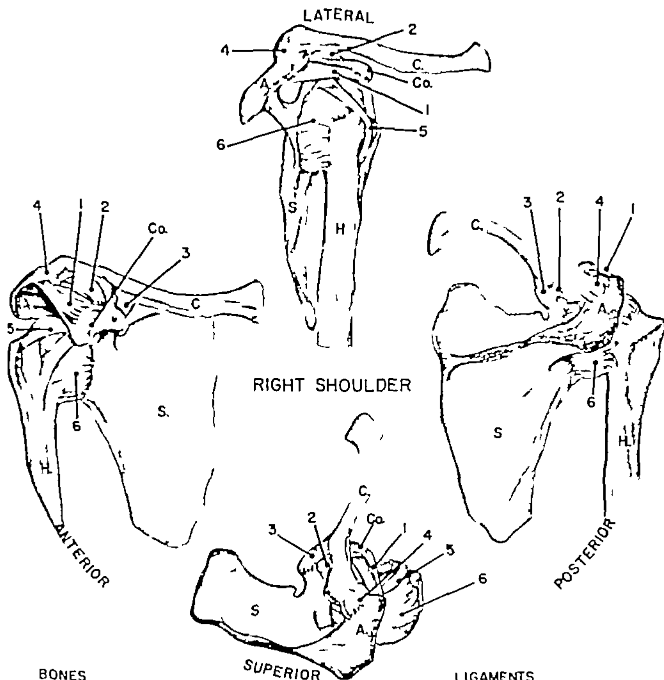
NERVES —The shoulder has an adequate overlapping nerve supply The trunks of the brachial plexus pass posterior to the middle third of the clavicle into the axilla and thence to the arm. Gardner has demonstrated clearly the complete nerve supply to the capsule and rotator muscles of the shoulder

BLOOD SUPPLY —The shoulder is generously supplied with blood except for one important area, the tendinous portion of the supraspinatus muscle This poorly nourished area shows attritional changes in advancing decades owing to its repetitious motion under the overlying acromion

Function

Codman in his book, *The Shoulder* illustrates uniquely the functional development of the shoulder In quadripeds the shoulder functions as a swinging pendulum. In the erect position of bipeds (as in man) however the shoulder must function as a lever arm thus adding definite strain to the shoulder mechanism Codman also describes "scapulohumeral rhythm which is the smooth reciprocal functioning of the shoulder girdle muscles

Inman Saunders and Abbott in 1944



BONES

A acromion
C clavicle
Co. coracoid
S scapula
H humerus

LIGAMENTS

1 coraco acromial
2 trapezoid } coracoclavicular
3 conoid } coracoclavicular
4 acromioclavicular
5 biceps tendon (long)
6 capsular

Fig 165 —Bones and ligaments of the shoulder girdle

C5
C6
C7
C8
T1
Rib I
Reflected Deltoid
Divided Pectoralis Major
Subscapularis
Pectoralis Minor
Biceps
Long head
Short head
Teres Major

C5
C6
C7
C8
T1
Brachial Plexus
Clavicle
Acromion
Supraspinatus M
Infraspinatus M
Teres Minor M.
Reflected Deltoid M.
Circumflex Nerve
Radial N & A. exposed by cutting Triceps Medial and Lateral head
Teres Major M.

Fig 166 —Muscles of the shoulder girdle. Top anterior aspect Bottom posterior aspect.

supplied further information regarding the mechanism of total shoulder motion

The important points concerning shoulder motion are

1 *In the first 45 degrees of abduction* The scapula does not rotate but "sets itself" The short rotators depress the head of the humerus allowing the deltoid muscle to elevate the arm Early motion is noted in the sternoclavicular joint The clavicle is gradually elevated 25 degrees in the first 110 degrees of abduction

2 *Between 45 and 90 degrees of abduction* Scapular rotation begins and continues with a 1 2 ratio with the glenohumeral joint.

3 *From 90 degrees to complete elevation* The clavicle at 110 degrees elevation rotates 45 degrees Unless this rotation takes place shoulder elevation is limited at 110 degrees

The scapula rotates or pivots upward and forward on the chest wall and places the glenoid fossa directly under the head of the humerus thus quickly and efficiently adjusting to its optimum mechanical position in relation to the humeral head The pivoting motion and the "recoil" mechanism of the scapula lend definite stability to the function of the shoulder

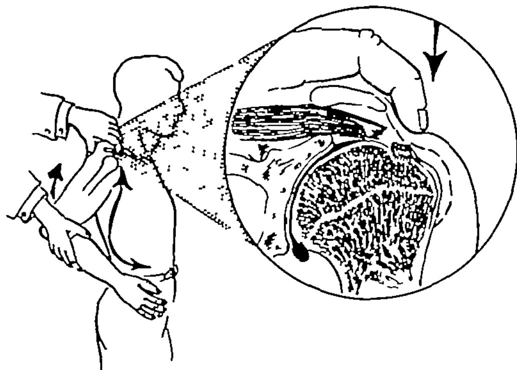


Fig 167 —Palpation of the rotator-cuff tendon

CLINICAL EXAMINATION

INSPECTION —Much can be learned from careful inspection of the shoulder girdle noting bony landmarks alignment atrophy and hypertrophy

PALPATION —The examiner should gently palpate the whole shoulder—joints muscles tendons and bones—for painful or unstable areas The rotator-cuff tendon can be examined by placing the fingers just beyond the acromion and rotating the arm at 45 and 90 degrees of abduction Sometimes a crunch eminence or a sulcus can be felt (Fig 167) The point of insertion of all muscles and tendons should also be palpated gently

MOTIONS —1 The patient should be instructed to bend forward at the waist to let the arms hang loosely and then to swing them gently forward and backward Next he should stand erect extend the arms in full elevation and then *slowly* lower the

arms in wide abduction. The examiner should watch from behind the patient the motions of the scapula, muscles and joints then he should repeat the instructions observing from the front. This is the "scapulohumeral rhythm" the most useful step in shoulder examination

2 The examiner should instruct the patient to stand erect, elbows at side to flex the forearms to 90 degrees and to execute external and internal rotation The patient should abduct the arm to 90 degrees and repeat the foregoing procedure in this position. Then he should put the hands behind the back.

Neurological Examination — With pin and cotton the examiner should map out areas of anesthesia or hyperanesthesia Loss of muscle power and atrophy should be noted and the biceps and triceps reflexes should be tested.

Cervical Spine, Elbow Wrist and Hand —These should be examined in order to complete the shoulder examination Figure 168 shows an analysis of 1 603 shoulder girdle injuries treated at the Massachusetts General Hospital

CLAVICULAR INJURIES

Anatomical Considerations — The

and lends efficiency to the functior glenohumeral joint The bone is lar more curved in the male than in male It presents a double curve its third is flattened horizontally wh medial two thirds is rounded or pr in shape Its cross-section varies as in Figure 169

The clavicle articulates to the s with a well-developed joint, the clavicular joint and to the acromic

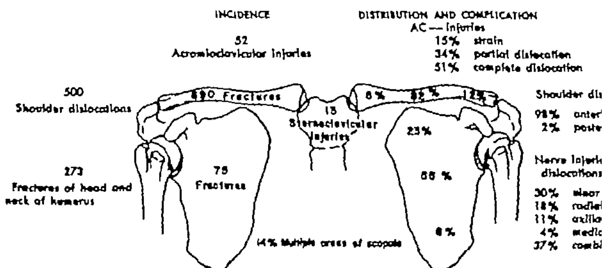


Fig 168 —Analysis of 1 603 shoulder girdle injuries showing the number and distribu fractures and dislocations

a rather imperfect joint, the acromio ular joint. The stability of these jo produced principally by their superi ticular ligaments and the coracoclav ligaments (the conoid and trapezoic ments) Stability and motion are ess in both the sternoclavicular and acr clavicular joints in order to allow ele and rotation of the clavicle and thus plete elevation of the shoulder

ACROMIOCLAVICULAR INJURIES

Incidence of Injury

It has been found that the acromioc ular joint is injured approximately times as frequently as the sternoclavi joint. Anatomically the acromioclavi joint is much weaker and more vulne to injury than is the sternoclavicular

pital indicate that the majority of the acromioclavicular injuries occur in the second decade of life but that there is a fairly even distribution otherwise from 20 to 60 years of age

Mechanism of Injury

Injury to the acromioclavicular joint is usually produced by a forceful depression of the tip of the shoulder with the arm in abduction and slight internal rotation

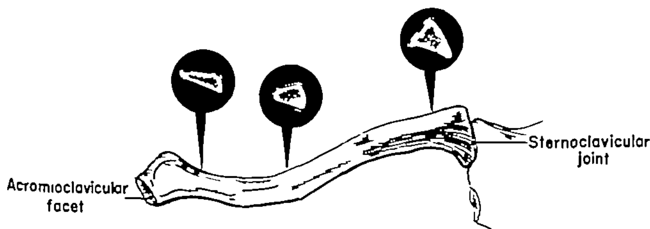


Fig 169 —Cross-section of the clavicle

Types of Injury

An analysis of the acromioclavicular joint injuries treated at the Massachusetts General Hospital shows the following types of injuries strain 15 per cent partial subluxation 34 per cent and complete dislocation, 51 per cent In acromioclavicular strains incomplete tears of the acromioclavicular articular ligaments occur In the partial acromioclavicular subluxation there is usually partial rupture of the capsule ligament and the coracoclavicular ligaments In complete upward dislocation of the clavicle there is complete rupture of both the acromioclavicular articular ligaments and the coracoclavicular ligaments

Diagnosis

The diagnosis of an acromioclavicular injury is usually not difficult

Inspection —The patient should be stripped to the waist for examination of both shoulders In complete dislocations the injured shoulder will show a marked prominence of the outer end of the clavicle Local ecchymosis may be present

Palpation —Local tenderness is elicited on palpation over the acromioclavicular joint The prominence of the clavicle may be increased by a downward pull of the arm and decreased by an upward and backward positioning of the shoulder

X ray —With the patient standing anteroposterior films of both shoulders should be taken. Weights held in both hands may increase the displacement of the injured side

Treatment

Treatment of acromioclavicular injuries depends on the severity of the injury the age and the occupation of the patient Strain and partial subluxations are more common in the younger age groups and respond well to strapping and rest (Fig 170)

In complete acromioclavicular dislocations early open reduction and repair with fascia lata give uniformly good results not only in appearance and function but by a shorter convalescence Elimination of the inconveniences of external apparatus in adults is also a very important factor Following open reduction and repair only 1 patient in 20 showed less than a good result

At the Massachusetts General Hospital a number of adult patients have been seen

with complete acromioclavicular disloca tion which was not reduced The cosmetic appearance is not disturbing to the male but is a definite consideration in the female patient. Function is fair to good however since there are no apposing articular sur faces The outward end of the clavicle is completely displaced above the articular surface of the acromion In practically all of these cases symptoms of strain are present.

OPERATIVE TREATMENT —The purpose of an open reduction (Fig 171) should be to produce stability of the acromioclavicu lar joint and to preserve clavicular motion The surgical exposure must be adequate so that both the coracoclavicular and the acromioclavicular ligaments can be thor oughly inspected *The surgical repair is usually made with fascia*

The technical steps for open reduction are as follows

1 *Position of the Patient* Semisitting position with the affected shoulder elevated

2. *Exposure* Anterior shoulder expo-sure should be carried out to allow com plete inspection of the acromioclavicular and the coracoclavicular ligaments

3 *Repair* It is important to repair both the superior articular ligament and the coracoclavicular ligaments Some means of internal fixation is necessary during the healing period of the ligaments This may be accomplished very effectively with the 3/32 inch Kirschner pin introduced under direct vision across the acromioclavicular joint from the acromion into the clavicle The wire or pin should be left in situ for 4–8 weeks The superior articular ligament of the acromioclavicular joint and the coracoclavicular ligament are then re-paired with silk sutures At the Massachu setts General Hospital the repair of the coracoclavicular ligaments has been rein forced with fascia lata in the majority of patients This material is obtained through a 1 inch incision on the lower thigh using a fascial stripper The strip of fascia is

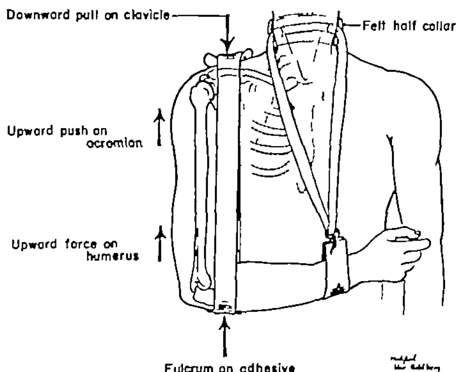


Fig 170 —Mechanical principles of the sling used for acromioclavicular separation. (After Goldberg, D Acromio-clavicular joint injuries—a modified form of treatment, Am J Surg. 71 529 1946)

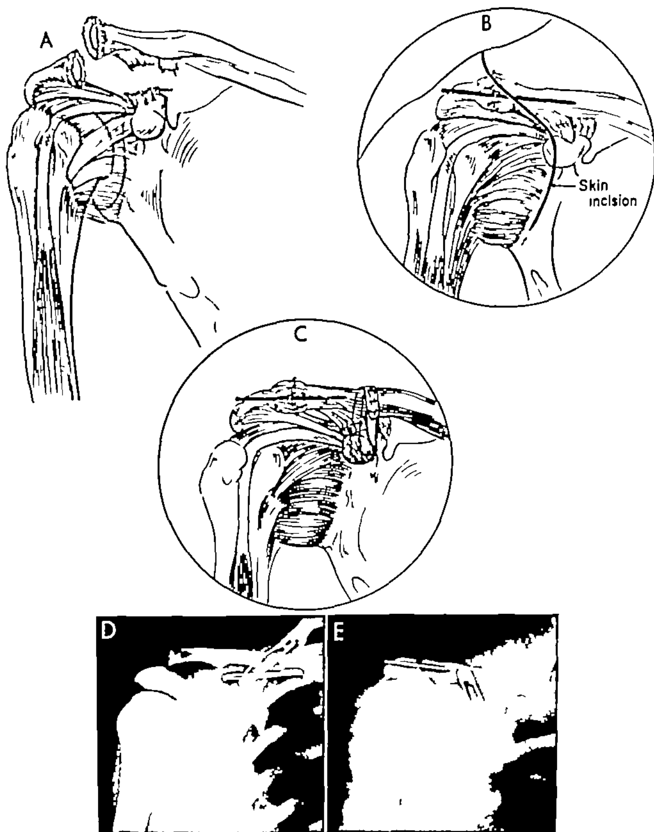


Fig 171 —Open reduction for complete separation of the acromioclavicular joint A diagram of the dislocation B Kirschner-pin 3/32 inch fixation with direct repair of supra articular acromioclavicular ligaments and coracoclavicular ligaments C repair with fascia lata D roentgenogram showing complete separation of the acromioclavicular joint in a woman aged 52, which resulted from being thrown from a horse E direct repair of ligaments and temporary Kirschner-pin stabilization Follow up rating 1 year later was excellent

passed over and around the clavicle and down around the coracoid It gives added stability but does not eliminate the rotation action of the clavicle It is not necessary to pass the fascia through the clavicle or through the acromioclavicular joint.

After Treatment — Support to the shoulder by means of a sling and swathe is necessary for a period of a week to 10 days after which only a sling may be needed for another week. Muscle-setting exercises and pendulum exercises are begun early At the end of 6–8 weeks the pin may be removed and light work undertaken. Heavy work can probably be resumed within 3 months

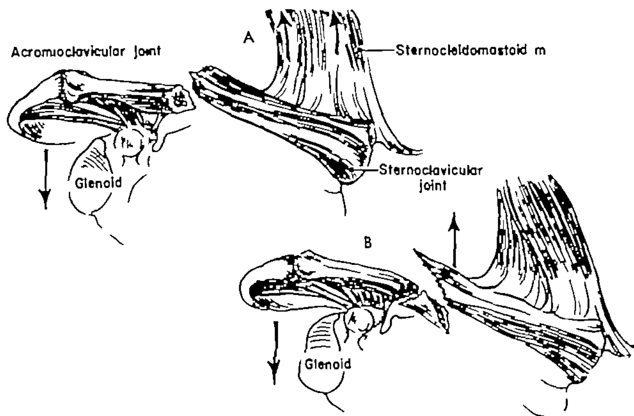


Fig 172.—Typical deformity of a clavicle fracture with upward pull on the medial fragment and downward displacement of the distal fragment A, transverse fracture B comminuted fracture

Complications

Fractures were associated in 6 per cent of the cases at the Massachusetts General Hospital and nerve injury recorded in only 1 case There were no serious vascular complications End result x ray films usually indicated ossification of the fascial strips

STERNOCLAVICULAR DISLOCATIONS

Incidence of Injury

Sternoclavicular dislocation was relatively uncommon Only 13 patients with this condition were seen in the past 15 years. The majority of the injuries occurred in the second decade of life

Mechanism of Injury

Injuries to the sternoclavicular joint, as with the acromioclavicular joint, were produced most frequently by a fall on the point of the shoulder (70 per cent of the cases) or by a direct blow to the clavicle (30 per cent of the cases) The clavicle is usually forced upward and outward but in 1 pa

tient the inner portion of the clavicle was displaced posteriorly by a direct blow

Diagnosis

The diagnosis is made with little difficulty

Inspection —A prominence is present at the sternal end of the clavicle Local ecchymosis and swelling may be present

Palpation —Local pain and instability of the inner end of the clavicle are present In fresh cases the dislocation can usually be reduced by extension and elevation of the shoulder It can be reproduced by forward flexion and depression of the shoulder

X ray — Anteroposterior and oblique views will usually demonstrate the dislocation of the sternoclavicular joint

Treatment

Effective closed reduction of the sternoclavicular joint is difficult or impossible to maintain Adhesive strapping may give symptomatic relief but will not hold the reduction of the dislocation. Complete dislocation, particularly in a vigorous active individual requires early open reduction. The operative repair may consist of lashing the sternal end of the clavicle to the first rib with fascia or by passing the fascia through articular drill holes from the clavicle to the sternum In old unreduced sternoclavicular injuries reduction is difficult and should not be attempted since fibrous tissue and traumatic changes prevent satisfactory reduction If symptoms are severe resection of the inner end of the clavicle will give the best results

FRACTURES OF THE CLAVICLE

Mechanism of Injury

Fractures of the clavicle usually result from falling on the extended arm or from a direct blow to the shoulder They occur most frequently at the junction of the middle and outer thirds of the bone Because of such a fracture the shoulder is displaced downward and inward, while the proximal end of the clavicle is elevated (Fig 172)

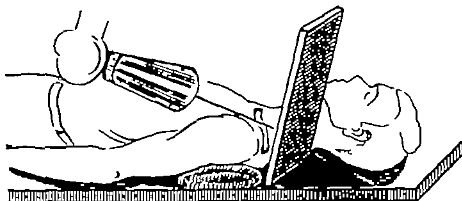


Fig 171 —The oblique view of the clavicle is taken with the tube resting on the patient's chest and the film in the vertical position behind the shoulder

Diagnosis

Inspection —The patient with a fractured clavicle has a typical appearance He leans forward slightly supporting the injured arm at the elbow and holding it close to the body Any change in this position may cause pain

Palpation —Local pain swelling and crepitation are usually present over the fracture site

X ray —At times the diagnosis of a fractured clavicle can be very difficult. Anteroposterior films of the clavicle may fail to show a fracture line Lateral or oblique views are often useful in demonstrating a

fracture line which may not be clearly visualized in routine films (Fig 173)

Treatment

Because the typical deformity is depression of the shoulder reduction is achieved by replacing the shoulder upward and backward Reduction may not be necessary in infants and in young children but it is desirable in adolescents and adults This is usually accomplished by placing the patient on a stool and drawing the shoulders back or by having the patient lie supine on a fracture table with a small perineal rest or bar between the shoulder blades As a rule an anesthetic is not necessary If needed, however 5–10 cc of 1 per cent procaine can be used locally

Methods of Immobilization —The methods of immobilization (Fig. 174) vary with the age of the patient.

Infants —Usually a hank of knitting wool used in a figure-of-eight around the shoulders will be effective

Children —A figure-of-eight webbing made from Webril® and Ace® bandages will give comfort and support However frequent adjustments are necessary

Adults —In adults the problem is to *maintain reduction The simplest method* is complete rest for 3 weeks with the patient flat in bed on a firm mattress with a slight raise between the shoulder blades. This is usually impractical some ambulatory device is required Interscapular rings or adjustable shoulder braces with figure of-eight webbing around the shoulders can be very effective but require frequent adjustments One must watch for axillary irritation or pressure from figure-of-eight apparatus A clavicular cross or a modified shoulder plaster spica can be used The latter can be applied with the patient sitting or lying Before the plaster sets the patient should be upright so that careful molding of the jacket posteriorly between the scapula and anteriorly in the pectoral region will maintain the shoulder upward and backward Clothing can be worn over the spica and the patient may return to many of his usual activities Usually no change in the plaster is necessary until the fracture has healed.

Duration of Treatment —The expected period of healing for fractures of the clavicle may be estimated as follows

Infants 10–12 days
Children 3 weeks
Young adults: 4–6 weeks
Adults 6 weeks or longer

Operative Treatment — In certain cases in which there is marked displacement and angulation of the fragments open reduction and intramedullary pinning are required. The operative technique is illustrated in Figure 175 and described below

Position of the Patient —Semisitting with elevation of the injured shoulder Sandbags or folded blankets are placed under the shoulder blades The tip of the shoulder should point toward the ceiling The entire extremity is prepared and draped.

Reduction of the Fracture —1 A 2 to 3-inch linear incision is made parallel to and just above or below the clavicle (Fig 175 *A*) Extreme care must be taken in exposing the fragments to avoid injury to the subclavian vessels or brachial nerves.

2. A 3/32 *inch Kirschner wire or pin* is drilled from the fracture site through the medullary canal of the outer fragment until it pierces the skin behind the acromion (Fig 175 *B* and *C*) The Kirschner pin is drilled outward until the base of the pin is at the fracture site

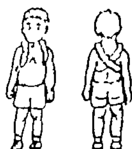
3 With the Kirschner pin driven to the fracture site the drill is removed from the pin.

4 The fracture is then reduced under direct vision

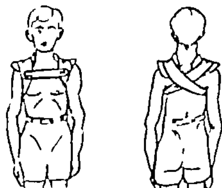
5 The drill is next attached to the projecting pin behind the acromion

6 The pin is then "backed" into the medullary cavity of the proximal fragment of the clavicle for a distance of 2–3 cm until it strikes the cortex of the middle third of the clavicle (Fig 175 *D*) *The blunt end of the pin cannot penetrate the cortex*

7 The posteriorly projecting pin is fi

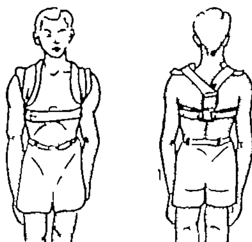


INFANTS
Hank of wool



CHILDREN
Webril® and Ace®

Webbing and ring



TEEN AGERS
and
ADULTS

Plaster spica

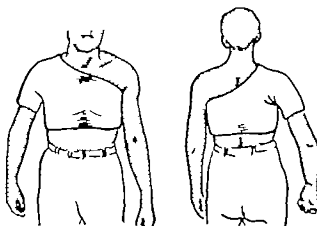


Fig 174 —Typical splints for fractures of clavicle at different ages

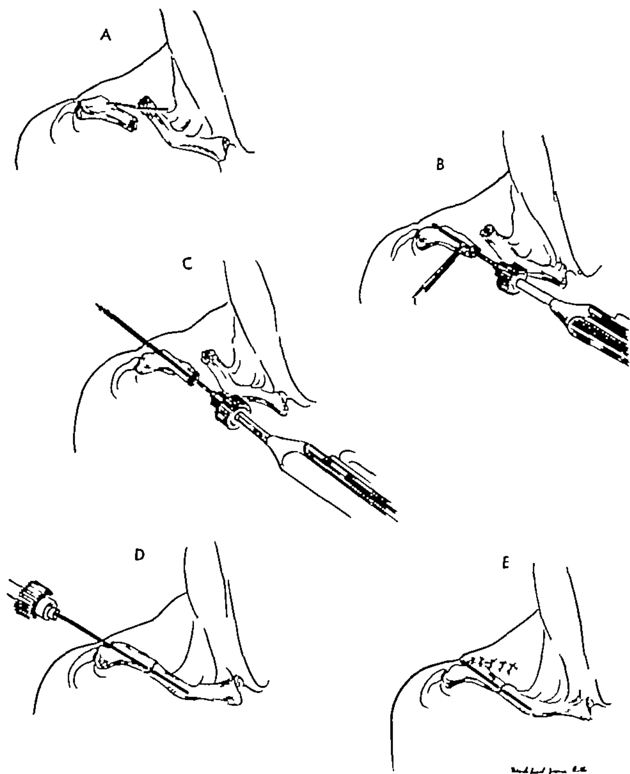


Fig 175 —The technical steps in open reduction and intramedullary fixation of a fractured clavicle using a 3/32 inch Kirschner pin (See text)

nally cut off below the skin (Fig 175 *E*)

No cases of nonunion have occurred at the Massachusetts General Hospital following this technique although several instances of delayed union were experienced because of removing the pin too early The pin should be left in for a period of 8–10 weeks. If the pin works out it will extrude posteriorly *in the line of least resistance* No instance of extension of the pin proximally into the chest space occurred in this series of cases Such extension cannot occur if the cortex of the proximal fragment is not penetrated and if the procedure is carried out by directly exposing the fracture site In cases of nonunion of the clavicle iliac or rib grafts are placed subperiosteally around the fracture site Figure 176 illustrates an open reduction of a fractured clavicle with intramedullary pin fixation



Fig. 176 —**Left** unsuccessful closed manipulation of a fractured clavicle in a male aged 19 which was due to interposition of muscle at fracture site **Right** open reduction with 3/32 inch intramedullary Kirschner pin

FRACTURES OF THE SCAPULA

Incidence of Injury

In a series of 75 fractures of the scapula treated at the Massachusetts General Hospital the majority of the patients received the injury when they were aged 40–60 years 32 per cent were in the 50 s Most of these fractures involved the middle third of the scapula including the glenoid and in the neck of the scapula

Complications

A fracture of the scapula may be considered a fracture with associated injuries for some type of associated injury occurred in 72 per cent of the patients in this series The incidence of other fractures in addition to the scapular fracture was 45 per cent. This is understandable since the scapular fracture is usually the result of a forceful direct blow to the torso Pneumothorax and subcutaneous emphysema occurred in 3 per cent of the patients and injuries to the brachial plexus in 4 per cent. Dislocations complicating this fracture occurred in 12 per cent of the patients 7 per cent of them having a dislocated shoulder

Diagnosis

Much may be gained from a careful inspection. Local contusion or subcutaneous hematoma formation may indicate scapular injury A consistent sign is marked limitation of all shoulder motions because of pain The patient usually supports his arm close to his body In evaluating patients with scapular fractures the examiner must

be mindful of other injuries particularly injuries to the ribs and lungs

X RAYS —Anteroposterior and oblique tangential views will usually demonstrate scapular fractures

TREATMENT

In general fractures of the scapula heal readily and respond satisfactorily to conservative measures

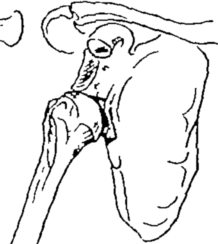
FRACTURES OF THE BODY OF THE SCAPULA —Fractures of the flat surface of the scapula are treated with rest and support As a rule overlying subcutaneous hematomas will absorb Support is given to the shoulder by means of a sling for 3 weeks followed by active exercises

FRACTURES OF THE SPINE OF THE SCAPULA AND OF THE ACROMION —Displaced fractures of the acromion in which there is interference with the motion of the humeral head require manipulation or open reduction Such treatment is rarely necessary if the acromial fragment is small Instead the fragment may be removed. In general depressed fractures of the spine of the scapula do well with no treatment

FRACTURES OF THE GLENOID FOSSA AND NECK OF THE SCAPULA.—All degrees of glenoid fractures may occur ranging from linear undisplaced fractures of the fossa to severe bursting fractures with mesial displacement of the humeral head In x ray views these are distressing looking, but very little can be gained by open reduction to improve the final functional result. Initial traction in abduction may give comfort. This may be followed in 10–12 days with early mild pendulum exercises in the standing position, with support to the shoulder by means of a strapping dressing or a sling

Open reduction may be necessary in rare instances but this should be carefully considered since closed treatment usually brings good response with early active function The most direct approach to the glenoid fossa is through the posterior shoulder exposure (see Surgical Approaches to the Shoulder Joint p 285)





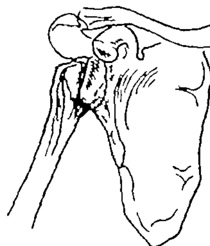


Fig 177 —Types of shoulder dislocations.

DISLOCATIONS OF THE SHOULDER

INCIDENCE OF INJURY

From a study of 500 shoulder dislocations at the Massachusetts General Hospital it was found that the dislocations occurred as frequently after age 45 as be-

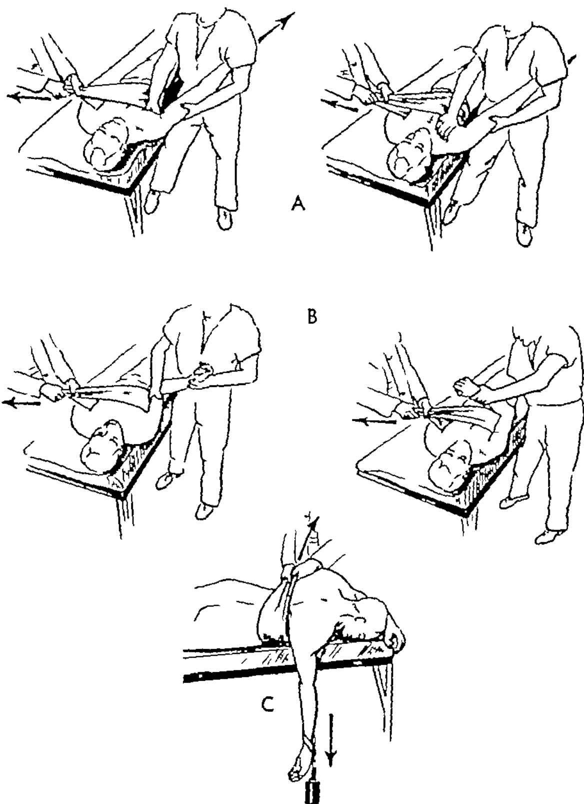


Fig. 180 —Methods used in closed reduction of an anterior dislocated shoulder A, traction and fulcrum method B Kocher method C, Stimson traction method

was admitted to the hospital because of superimposed trauma to the shoulder The surgeon was greatly embarrassed when he found after making a completely unsuc cessful attempt at reduction that the shoul

Pentothal® sodium is usually adequate but occasionally Anectine® may be very helpful The method of reduction used almost routinely at the Massachusetts General Hospital is the traction and fulcrum



Fig 181 —Simple methods of shoulder support. Top front and back views of the sling and swathe or "double sling" support. Bottom the "wrap-around" sling

der had been dislocated for 10 years or more

The methods of reduction are shown in Figure 180 and described below

TRACTION AND FULCRUM METHOD — Some shoulders reduce very easily some with great difficulty Much depends on the build of the patient and the length of time that the shoulder has been dislocated Adequate anesthesia or analgesia is necessary

method (Fig 180 *A*) which is essentially the hippocratic method that was completely outlined in Sir Astley Cooper s textbook in 1825 The steps in the procedure follow

1 Countertraction is applied by a folded sheet placed high in the axilla

2 "Slow and steady" traction is applied to the arm in moderate abduction with the elbow straight or in 90 degrees flexion If

the operator grasps the arm in his axilla he will have both hands free to guide or manipulate the head of the humerus

3 After traction has been applied for several minutes the humeral head can be manually lifted into its natural position or the operator s hand may be used as a ful crum to replace the head upward into the glenoid fossa. In some cases a longer period of traction may be needed before the head is movable

KOCHER METHOD —The Kocher method (Fig 180 *B*) has been used less frequently than the traction and fulcrum method Steps in the Kocher maneuver are

1 Gentle traction is applied in line of deformity with the elbow flexed to 90 de grees Gradually the arm is externally rotated

2 With the arm in external rotation and under steady traction the extremity is ad ducted across the chest and internally rotated This will usually reduce the shoul der A rapid grinding maneuver should be avo'ded *A word of warning* Avoid force The surgeon must be mindful of the possi bility of fractures of the humerus occurring when this maneuver is used in elderly pa tients or in old dislocations

STIMSON METHOD —If reduction is un successful the patient may be turned face down and a weight applied to the dislocated arm for a period of 5–15 minutes (Fig 180 C)

AFTER-CARE.—After reduction, x ray films should be made they will show the position of the head in relation to the glenoid and the presence or absence of con comitant fractures Then the axilla should be powdered an axillary pad applied and the shoulder supported in internal rotation and adduction with a sling and-swathe or a Velpeau bandaging (Fig 181 *top*) If support is to be used for several weeks the "wrap-around" sling (Fig 181 *bottom*) is very effective in maintaining internal rota tion and adduction

LENGTH OF IMMOBILIZATION —Follow up statistics at the Massachusetts General Hospital indicate that the incidence of recurrent dislocations drops off rapidly at 50 years of age Therefore in persons over 50 the shoulder should be immobilized for a short time only Active exercises should be begun early in order to maintain maximum range of motion and function. The incidence of recurrence in the second and third decades however is very high and in this age group immobilization should be maintained for 5–6 weeks

During the period of immobilization ac tive use of the hand wrist, and elbow should be begun immediately with deltoid setting exercises for the shoulder These exercises to be effective are best per formed slowly and repeatedly during the day

Recurrent Anterior Dislocation

Operative repair is indicated in disloca tions which recur frequently and thus become a disability The primary requirement for operative repair regardless of the method employed is an adequate surgical exposure for without this the pathological anatomy associated with the dislocation cannot be identified and thereby corrected The operation should have as its aim the restoration of a stable shoulder with a useful range of motion.

The method of shoulder repair used by the majority of the staff at the Massachu setts General Hospital is the Bankart opera tion or some modification of this procedure This operation has proved extremely satisfactory

From experience and from the reports of operative procedures in follow up studies in the literature the following techniques (described below) are standing the test of time and have a relatively low rate of recurrence the Bankart (1–5 per cent recurrence) the Putti Platt (5 per cent recur rence) the Gallie–Le Mesurier (4 per cent recurrence) the Hybbinette-Eden (6 3 per cent recurrence) and the Magnuson-Stack (2.45 per cent recurrence)

The Nicola procedure has a higher rate of recurrence when used in young active individuals but may be used very effec tively in the less active age groups The

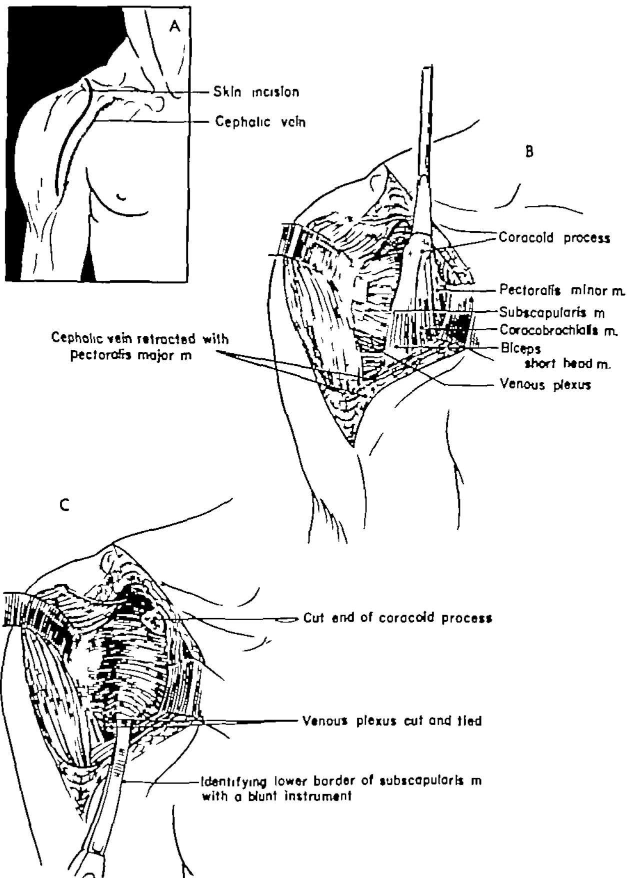


Fig. 182.—Operative steps in Bankart repair for recurrent, anterior dislocation of the shoulder A, skin incision B deltoid m turned outward osteotomy of coracoid process allowing it to retract mesially C exposure of subscapularis m and identification of its lower border (continued)

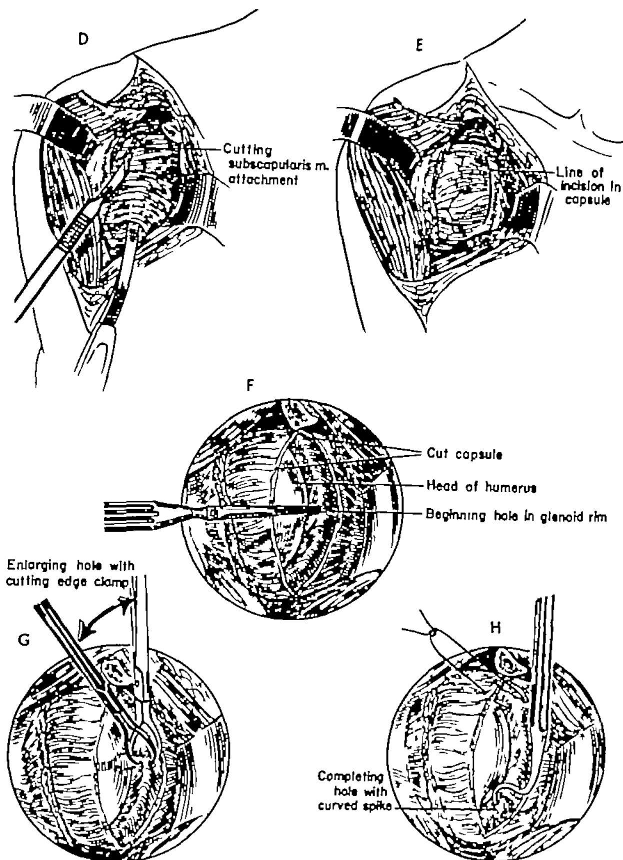
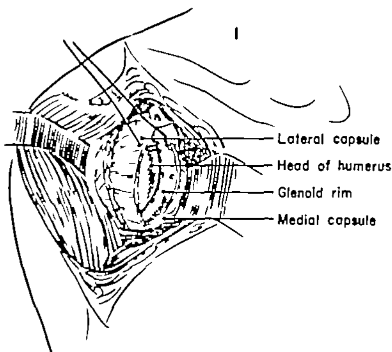


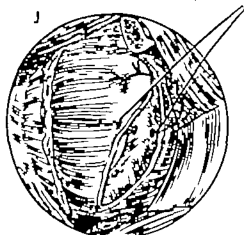
Fig 182 (cont) —D separation of subscapularis m and tendon from the anterior capsule E incision through the anterior capsule along the glenoid rim F three holes are made in the anterior glenoid rim at 1 o clock 3 o clock and 5 o clock. G and H use of the sharp edged clamp and spike to complete the holes (continued)

Dickson operation has not had the test of time The Henderson sling operation and the Clairmont Ehrlich procedure have been uniformly unsuccessful in the experience of the staff at Massachusetts General Hospital Fracture Clinic.

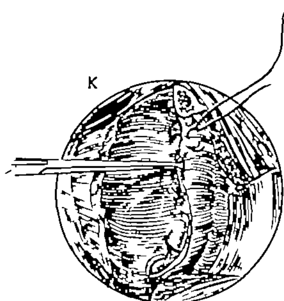
placed in the semisitting position with the injured shoulder elevated The entire extremity is surgically prepared and draped so as to be available for maneuvering by the surgeon

Skin Incision —The skin incision ex





Suturing lateral flap of capsule directly to glenoid rim



Double breasting medial capsule flap over the lateral capsular repair

Fig 182 (cont) —I and J suture of lateral capsular flap to the glenoid rim K double breasting of the medial capsule (continued)

THE BANKART REPAIR (Fig 182) —*Object* —Reattachment of the capsule to the anterior bone margin of the glenoid thus creating a fibrous barrier along the antero-inferior glenoid rim

Position of the Patient —The patient is

tends (Fig 182 *A*) from the outer third of the clavicle down the anterior aspect of the shoulder The deltopectoral junction is identified The cephalic vein which divides these two muscles may be ligated or retracted with the pectoralis major or deltoid

muscle (Fig 182 *B*) Several small veins from the thoracoacromial plexus may be present in the upper third of the incision these should be identified and ligated

Shoulder Exposure —The anterior deltoid muscle is separated from the outer third of the clavicle for a distance of about 2 inches This is accomplished effectively by incising through the "white tissue"—i e the aponeurotic junction between the trapezius and the deltoid muscles along the clavicle Deltoid-splitting incisions for this procedure are discouraged because they limit the exposure and may result in injury to the axillary nerve

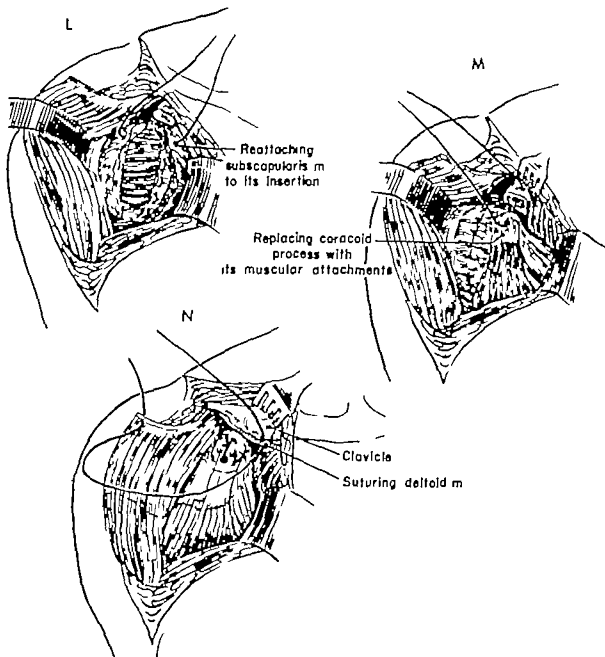


Fig 182 (cont) —L, reattachment of the subscapularis m M, reattachment of the coracoid process N reattachment of the deltoid m.

The coracoid process may or may not be osteotomized As a rule osteotomy is preferred because it allows the attached muscles to retract mesially toward the chest wall Prolonged traction to these muscles

may injure the musculocutaneous nerve which supplies the biceps and the coracobrachialis muscles Before osteotomizing the coracoid a hole should be made *through it with a small gouge*

The subscapularis muscle is outlined by externally rotating the arm The lower border of the muscle is identified by the "marginal veins" (the anterior humeral circumflex veins) These are ligated separately with a suture ligature The surgeon then passes his finger or a blunt instrument up under the subscapularis muscle (Fig 182 *C*) and estimates the portion of the tendon which is attached to the capsule and to the lesser tuberosity By sharp dissection the musculotendinous junction of the subscapularis muscle is freed from its attachment to the underlying capsule and allowed to retract mesially (Fig. 182 *D*) The muscle is marked with several silk stay sutures

The *capsule is then carefully examined* The arm is *externally* rotated and a 2 to 3-inch vertical incision is made into the capsule along the anterior glenoid rim (Fig. 182 *E*) If the incision in the capsule is made with the arm in external rotation the patient will regain external rotation more readily after the operation.

Repair —With the capsule open the shoulder joint is carefully examined Loose bodies if present are removed and the condition of the humeral head is noted The glenoid labrum is usually found to be injured but it may be completely missing The anterior glenoid rim is freshened with a small osteotome or curet Three holes (Fig 182 *F*) are made in the anterior glenoid rim ¼ or ⅜ inch apart. A variety of instruments is used to accomplish this A small, straight gouge may be used for perforating the cortex of the bone and then the hole completed with a sharp three-edged clamp (Fig. 182 *G*) or a curved spike (Fig. 182 *H*) made especially for this purpose Braided silk or #20 cotton is then passed through the holes by means of a medium curved *needle or a small hooked* retriever

The lateral flap of the capsule is secured directly to the glenoid rim by the silk sutures (Fig 182 *I* and *J*) The medial flap of the capsule is then plicated over this attachment by interrupted sutures (Fig 182 *K*)

The *subscapularis muscle is reattached* at its original point of insertion (Fig 182 *L*) Some surgeons prefer to advance the attachment laterally or inferiorly

The coracoid process is reattached with braided silk through the previously made hole and with two lighter sutures is reinforced by fastening it to the mesial and lateral side of the tendinous attachment (Fig 182 *M*)

The deltoid muscle is reattached to the aponeurosis of the clavicle by using interrupted fine sutures (Fig 182 *N*) and the skin is closed

After Treatment —For 10 days the arm is supported close to the body by means of a "wrap-around" sling or a Velpeau bandage *An ordinary sling is then used for* 2 weeks during which time deltoid exercises may be carried out After this free motion of the arm is allowed with increasing resistive exercises for the deltoid muscles On this schedule the arm should be usable for light activities in 6–8 weeks and should have a good range of motion within 6 months In some cases maximum range of motion is not obtained for a year There may be various degrees of permanent limitation of motion of the shoulder in external rotation and abduction

THE PUTTI PLATT PROCEDURE (Fig 183) —*Object* —Overlapping and shortening ("double breasting") the subscapularis tendon

Approach —The anterior portion of the shoulder is used

Division of the Subscapularis Tendon — The arm is externally rotated identifying the upper and lower portions of the subscapularis muscle The surgeon's finger or a blunt instrument is then passed under the subscapularis muscle and the tendon is divided approximately 1 inch from its insertion into the lesser tuberosity The incision is carried down directly through the muscle and capsule The joint is opened and inspected

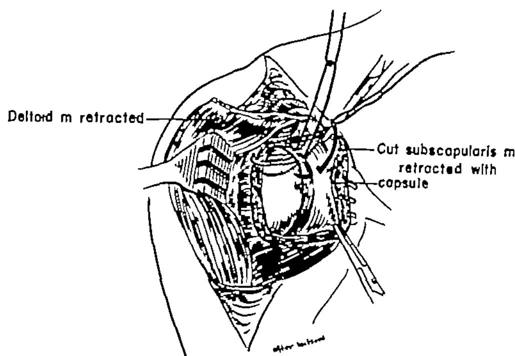


Fig 183 —The Putti Platt procedure. (From Osmond-Clarke H J Bone & Joint Surg. 30-B 23 1948)

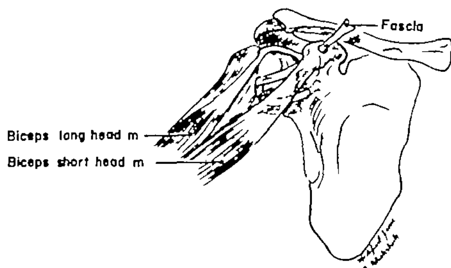


Fig 183 1 —The Gallie-Le Mesurier procedure (From J Bone & Joint Surg 30-B 14 1948)

Repair —The lateral stump of the subscapularis tendon and capsule is attached to the anterior glenoid rim or the neck of the scapula This is done with the arm in internal rotation Here the technique varies somewhat. Some surgeons suture the ten don to the labrum (if intact) to the glenoid rim or to the periosteal tissues along the scapular neck. The mesial portion of the capsule and of the subscapularis muscle is then "double breasted" over this repair and attached to the lesser tuberosity or bicipital groove This operation has given very stable reduction, but external rotation is more limited than in the Bankart procedure

After Treatment —The arm is supported at the side of the chest for 3 or 4 weeks This treatment is followed by a program of active exercises

THE GALLIE–LE MESURIER PROCEDURE

(Fig 183-1) —*Object* —Reconstruction of a "new ligament" (fascia lata) for the anterior capsule and the glenohumeral ligament.

Approach —Anterior approach to the shoulder similar to the Bankart approach

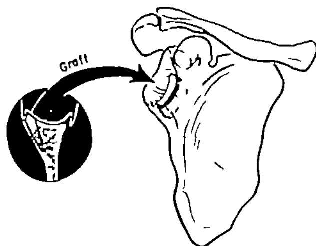


Fig. 184 —The Hybbinnette-Eden procedure

except that the subscapularis tendon is left attached and is retracted upward from its lower border exposing the underlying capsule.

Repair —With the forefinger of the left hand on the anterior glenoid rim a 3/16-inch drill is driven through the neck of the scapula from a point ½ inch from its lower border The drill is tapped gently onward until it reaches the skin below the scapular spine A 1 inch incision will expose the point of the drill A strip of fascia ½ inch wide and 10 inches long is removed from the thigh In one end a single knot is tied The fascial strip is then passed anteriorly through the drill hole leaving the knot posteriorly The fascia is next passed through the tunnel in the anterior humeral neck then through the coracoid The fascia is then split and sutured anteriorly to itself

After Treatment —The arm is supported across the chest. Abduction and external rotation are avoided for a month after which active exercises are begun. Gallie states that at first there is marked limitation of external rotation and abduction but that in the course of 3–4 weeks only slight limitation of external rotation persists

THE HYBBINETTE EDEN PROCEDURE (AFTER IVAR PALMER AND ANDERSON) (Fig 184) —*Object* —"Fixing" a bone graft (iliac crest) in the periosteal pocket of the anterior glenoid rim

Approach —The anterior shoulder approach is used

Repair —With the joint open the humerus is pulled down and outward allowing inspection of the glenoid and anterior joint capsule A subperiosteal pocket is made with a raspatory or osteotome along the anterior glenoid rim If the labrum is found attached the pocket is made between the labrum and the rim A bone graft measuring usually 1 × ¼ inch or according to the size of the pocket is taken from the iliac crest The graft is pressed down into the subperiosteal pocket so that the projecting part is lodged on the rim forming an anterior wall of bone For stability Eyre Brook transfixes the graft with a metal screw

After Treatment —The arm is supported in a sling for 2 weeks after which active

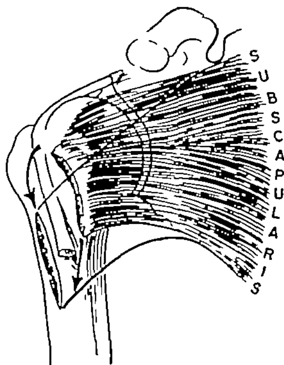


Fig 185 —The Magnuson Stack procedure

motion of the arm is begun but external rotation is avoided

THE MAGNUSON STACK PROCEDURE (Fig. 185) —*Object* —"The formation of a cup

of muscle or tendon around the lower or anterior part of the head of the humerus"

Approach —The anterior approach to the shoulder is used as in the preceding exposures

Exposure —The subscapularis tendon is identified and its borders above and below are freed The tendon with a wedge of bone is detached from its insertion at the bicipital groove The tendon is retracted mesially exposing the anterior capsule and

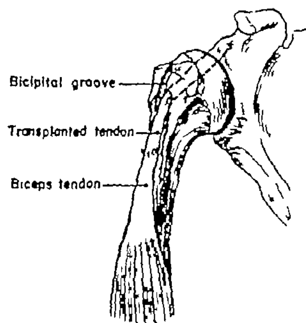


Fig 186 —The Nicola procedure

humeral head and also the glenoid rim The arm is then internally rotated and the tendon pulled around to a position below the greater tuberosity to the upper portion of the shaft of the humerus and attached here to a wedge-shaped gutter in the humerus The tendon may be sutured to the capsule or to the external rotator cuff for reinforcement This procedure extends the "wrap-around" effect of the subscapularis muscle and tendon to a lower position, thus becoming more effective when the shoulder is in elevation and external rotation

After-Treatment —The arm is supported across the chest by a Velpeau bandage for 2 weeks and then by a sling for 2 weeks Active exercises are then begun but external rotation and elevation of the shoulder are avoided for 8 weeks postoperatively

Permanent external rotation of 50 per cent may be present but function is satisfactory

THE NICOLA PROCEDURE (Fig 186) —*Object* —Transplantation of the long head of the biceps tendon through the head of the humerus

Approach —Anterior approach to the shoulder

Exposure —The tendon to the long head of the biceps is exposed by division of the transverse humeral ligament, or the "roof" of the bicipital groove Stay sutures ¼ inch apart are placed through the tendon 1 inch below the cut margin of the transverse humeral ligament. The tendon is divided proximally to the sutures

Repair —Just below the transverse humeral ligament a ¼ inch hole is drilled through the humeral head to the center or approximate center of the articular surface of the head Some surgeons aim for a point halfway between the center of the head and the articular border By means of a tendon passer the proximal tendon is passed from the joint through the humeral head and is reattached to its fellow tendon at the base of the groove

After Treatment —The shoulder is supported for a period of 2–3 weeks with a double sling or Velpeau bandage after which active exercises are begun

OLD UNREDUCED DISLOCATIONS OF THE SHOULDER

MANIPULATION —Closed manipulation if performed with care and gentleness may be attempted for dislocations which have been unreduced up to a period of 6 weeks With complete relaxation and prolonged traction and countertraction and with complete understanding on the surgeon's part of the inherent dangers of this maneuver reduction has been obtained in a number of old dislocations Force must never be applied and the use of repeated manipulations should be discouraged

OPEN REDUCTION —Open reduction should be considered when the initial maneuver has failed In dislocations older

than 6 weeks an initial open reduction should be carried out without attempting a closed manipulation

In an open reduction for an old unreduced dislocation adequate exposure is essential The surgeon should be prepared

The following conditions may be found at operation

1 The humeral head may be cleaved over the anteroinferior or the posterior glenoid rim Adequate preoperative x ray films should indicate this



Fig 187 —Posterior dislocation of the left shoulder in a man aged 45 Top this condition is usually not recognized on anteroposterior x ray views Bottom axillary views clearly illustrate posterior dislocation of the left humeral head

to expose the anterior as well as the superior and posterior aspects of the shoulder The deltoid muscle may be turned down from the clavicle the acromion and if necessary the spine of the scapula for necessary exposure This procedure can be extremely difficult—and in fact dangerous—if attempted without adequate exposure

2 The biceps tendon may be found dislocated from the bicipital groove across the glenoid fossa thus preventing reduction

3 The capsule and subscapularis muscle may be perforated by the humeral head (rare)

4 The capsule and labrum may be avulsed from their attachment to the an

teroinferior rim of the glenoid (common)

5 There may be partial or complete avulsion of the musculotendinous cuff attached to the head of the humerus

6 A mass of fibrous tissue usually fills the glenoid fossa in old dislocations. It is necessary to remove this in order to identify the fossa and reduce the dislocated head

Posterior Dislocations

Posterior dislocations may be divided into two types (1) the primary traumatic posterior dislocations and (2) the recurrent posterior dislocations

Diagnosis

Posterior dislocations are often difficult to diagnose and sometimes go unrecognized for months or years This has been found true in the experience of the staff at the Massachusetts General Hospital and has been emphasized by Wilson and McKeever and by McLaughlin. On casual inspection the examiner may see little However there are several helpful signs The patient s arm is in a position of internal rotation The arm *cannot* be externally rotated A helpful diagnostic procedure is to have the patient sit in a chair and to observe his shoulders from above *The injured shoulder will show* loss of the normal anterior roundness and possibly slight fullness posteriorly in the infraspinatus fossa On palpation in thin subjects the head of the humerus may be felt in the posterior position

X rays —In routine anteroposterior roentgenograms the shoulder may appear perfectly normal (Fig 187 *top*) Axillary views however will demonstrate the posterior dislocation (Fig 187 *bottom*) If necessary transthoracic or oblique views may be taken but as a rule good axillary views are sufficient.

Treatment

Primary Traumatic Posterior Dislocation —This injury is commonly accompanied by a history of a definite severe blow to the shoulder The head of the humerus is usually found wedged over the posterior glenoid rim

When there has been delay in recognizing this dislocation open reduction is necessary The "utility" shoulder incision is used Adequate exposure is necessary because there may be some difficulty in replacing the head of the humerus in the glenoid fossa. Reduction can usually be maintained by overlapping the external rotators When in doubt, a bone graft may be wedged posteriorly as in the anterior Hybbinette-Eden procedure or the lateral head of the triceps muscle may be transplanted to the posterior glenoid rim

Recurrent Posterior Dislocation —This condition occurs with little initiating trauma and is frequently associated with some degree of muscle imbalance Recurrent dislocations are usually produced from a position of forward elevation of the arm with some adduction In most instances the patient is able to reduce the dislocation Operative repair of this condition has been successfully carried out at the Massachusetts General Hospital by using the Bankart technique along the posterior glenoid rim.

Complications of Shoulder Dislocations

Injury to the Rotator Cuff —It is reasonable to assume that some degree of injury to the rotator cuff may occur in many traumatic dislocations of the shoulder particularly in elderly persons McLaughlin and Asherman have called attention to this possibility The dislocation may enlarge cuff tears which have been present prior to the dislocation or may create an entirely new tear

Nerve Injuries —In a series of 500 dislocations treated at the Massachusetts General Hospital in a period of 20 years nerve injuries occurred in 27 instances Of these nerve injuries 23 (85 per cent) were temporary whereas 4 (15 per cent) were permanent. Of the single nerve injuries the

ulnar nerve was injured in 30 per cent the radial nerve in 18 per cent the axillary in 11 per cent and the median nerve in 4 per cent of the total nerve injuries Combinations of nerve injuries occurred in 37 per cent of the whole group It was of interest to note that all single nerve injuries were temporary whereas combinations of nerve injuries included the permanent nerve injuries

ADHESIVE CAPSULITIS —This was uncommon in the younger age groups but was usually noted after age 35–40 Varying degrees of this condition were present

ing on 112 primary dislocations in 1956 are summarized as follows

Age of Patient	Incidence of Recurrence McLaughlin and Cavallaro	Rowe
Under 20	90%	83%
Between 20 and 40	60%	63%
Over 40	10%	16%

The significant fact is the high incidence of recurrence in the second and third decades of life and the sudden drop at age 40

Trauma —Perhaps the next most significant factor relative to the incidence or recurrence was the degree of injury at the



FIG. 188 —Anteroposterior views of the right shoulder showing the typical "hatchet" defect in the humeral head **Left** subglenoid dislocation before reduction **Right** postreduction (From Rowe C R. Prognosis in dislocations of the shoulder J Bone & Joint Surg. 38-A:967 1956)

RECURRENT DISLOCATIONS —A number of definite factors are related to the incidence of recurrent dislocations Listed in their importance these are (*a*) age of patient, (*b*) trauma in relation to initial dislocation, (*c*) defects in the superior lateral surface of the humeral head and (*d*) constitutional factors

Age —The most significant factor in relation to the incidence of recurrent shoulder dislocation was found to be the age of the patient at the time of the first shoulder dislocation. The findings of McLaughlin and Cavallaro reporting on 101 consecutive patients in 1950 and of Rowe report

time of the initial dislocation. Studies at the Massachusetts General Hospital suggest that the greater the initial injury causing the dislocation, the less the likelihood of recurrence It was interesting to note the very low incidence of recurrence when the shoulder was associated with a fracture of the greater tuberosity (7 per cent)

Humeral Head Defects.—The presence of a defect in the superior lateral surface of the humeral head was associated with an increase in the incidence of recurrence (Fig 188)

Constitutional Factors —A relatively small group of persons are predisposed by

nstitutional factors to have recurrent oulder dislocations Such dislocations oc r with little or no trauma to the shoulder

Pathology of Recurrent Dislocating Shoulders

It is generally conceded that no single thological finding accounts for recurrent oulder dislocations Rather they result om traumatic factors individual predis- sition and the natural unstable structure the shoulder The checking forces pre- nting dislocation of the shoulder are a mbination of muscle tone the envelop- g short rotators the protective pivoting *the scapula and the checking element* ong the anteroinferior glenoid rim com sed of the labrum and the attached cap- le In elevation and external rotation of e shoulder the capsule tenses and with lequate attachment plus the glenoid lab- m it functions as a check to the forward ding of the humeral head. The subscapu- ris muscle is also a definite factor in ecking the humeral head particularly in e position of elevation and external rota on of the shoulder However in extreme evation and external rotation the sub- apularis muscle moves upward and leaves e anteroinferior part of the head unpro- cted In the position of elevation also e neck of the humerus is in close contact ith the acromion a leverage point to force e head out of the joint

FRACTURES OF THE HEAD AND NECK OF THE HUMERUS

Diagnosis

Clinically there are no characteristic gns differentiating the various types of actures of the head and neck of the shoul er In general patients with these frac ıres present a painful swollen disabled ıoulder There is local pain on palpation nd motion of the shoulder The patient olds his arm close to his side

In undisplaced fractures there is no un sual change in the contour of the shoulder

In displaced fractures such as fracture dislocation of the head or shaft of the hu merus there is flattening of the shoulder contour The injured arm may be shorter than the opposite extremity Although fracture-dislocation of the shoulder is a severe injury it is surprising how fre- quently this condition is not recognized by ho examining physician or surgeon. In a number of patients with this injury the ini tial diagnosis was "severe sprain" or even "acute bursitis of the shoulder " Alteration of the contour of the shoulder may not be noted because of swelling and local tissue induration The appearance of ecchymosis within 48 hours should suggest a fracture

Treatment

Fractures of the Tuberosities and Impacted Neck Fractures

Fractures of the Greater Tuberosity (Fig 189) —The majority of the pa tients with greater *tuberosity fractures* do very well on a conservative regime Frac tures of the greater tuberosity complicated dislocations of the shoulder in 15 per cent of the 500 dislocations studied at the Mas- sachusetts General Hospital Usually the greater tuberosity is replaced in an accept able anatomical position by closed manip ulation or following reduction of the dis located shoulder In those cases in which the displacement was poorly reduced fairly good results were in time obtained Such injuries may require months of exercise be- fore the desired end result is reached In rare instances open reduction may be nec essary to replace the greater tuberosity

Impacted Neck Fractures (Fig 190) —The impacted neck fracture is a stable fracture therefore it responds well to sling support and early pendulum exercises The prognosis is good Bigelow in 1869 con cisely summarized the treatment of im pacted neck fractures Pad in the axilla Elbow at the side Arm in sling " Even though early activity may be possible in *impacted and greater tuberosity fractures*

maximum motion may not be obtained for 6-8 months

Displaced Fractures of the Head and Neck

Displaced fractures of the head and neck fall into two groups (1) fractures of the humeral neck with displacement of the shaft and (2) fractures of the humeral neck with dislocation of the head (fracture-dislocation of the shoulder) In the first group the shaft may be displaced mesially (most common) or laterally but the head remains in normal relation to the glenoid fossa In the second group the injury is more serious for permanent partial disability will result if the head is not reduced into the glenoid fossa The head may be displaced anteriorly or inferiorly or may be wedged over the rim of the glenoid fossa

NECK FRACTURE WITH DISPLACEMENT OF THE HUMERAL SHAFT (Fig 191) —If the displacement of the humeral shaft from the head is appreciable an attempt should be made to bring the shaft in alignment with the head by closed manipulation *Perfect anatomical reduction is not necessary for a good functional result* Reduction or improvement in position of the fracture is usually obtained by gentle traction on the humerus with the arm in 30–40 de-

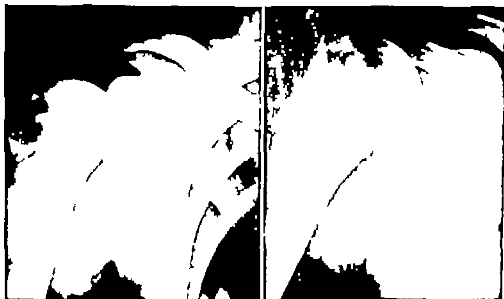


Fig 189 —Left fracture of greater tuberosity of humerus in a woman aged 35 treated conservatively with closed manipulation Right 1 year follow up excellent result.



Fig 190 —Left impacted surgical neck fracture treated with sling support and early exercise Right 1 year follow-up very good functional result



Fig 191 —Left angulation of a humeral neck fracture in an abduction (airplane) splint Right satisfactory alignment is obtained when the arm is brought to the side of the body



Fig 192.—Left fracture-dislocation of the shoulder in a woman aged 56 Right reduced by closed manipulation

grees of abduction and forward flexion almost in the position of a military salute If satisfactory reduction is not obtained then traction may be applied to the arm in adduction across the body Difficult cases have also been reduced by bringing the extremity into full elevation and then lowering it gradually to the side of the body It is generally accepted that the most stable position following reduction is that with the arm at the side of the chest and a folded towel in the axilla If traction is indicated a position of slight abduction and forward flexion may be used The old position of the arm in an airplane splint or 90-degree abduction is usually associated with loss of

reduction owing to the pull of the muscles on the distal shaft fragment (Fig 191)

FRACTURE DISLOCATION OF THE SHOULDER (Fig 192) —Recent fracture-dislocations should be given a trial with closed manipulation. This should be performed very carefully however and the vascular and sensory status of the extremity watched closely Traction should be applied to the arm in slight abduction or in line with the body With the operator s hand in the axilla the head may be lifted into the glenoid It is possible that if traction is applied with the elbow in extensión the biceps tendon may become tense and help realign the head to the shaft. Repeated manipulations should not be performed When one manipulation has failed open reduction may be indicated (or at least, further evaluation is indicated) In an elderly patient particularly



Fig 193 (top) —Left a displaced humeral neck fracture Right lag-screw fixation
Fig. 194 (bottom) —Left posterior fracture-dislocation of the humeral head Right a Rush nail was used successfully
Both of the above methods provided adequate stabilization and permitted early motion

a poor-risk patient it may be better to treat the patient symptomatically with a sling and early motion and to allow use of the extremity as tolerated by the patient In a young active person however open reduction would be indicated.

In old unreduced fracture-dislocations of long duration evaluation of the injury with consideration of the patient s age occupation and symptoms is most important In an active person in the twenties or thirties open reduction may be indicated In elderly patients conservative measures are indicated unless constant pain or nerve root pressure justifies open reduction

Open Reduction —The anterior shoulder approach may give the best exposure The incision may be extended down the shaft as far as necessary

Adequate exposure facilitates the reduction and fixation of this fracture The method and materials used for internal fixation will vary according to the conditions of the humeral head and the shaft. In a few patients reduction will seem stable and no internal fixation will be necessary As a rule however some form of fixation is indicated

Methods Used for Internal Fixation —

1 A lag screw (Fig. 193) gives good stability and allows early motion

2 A small blade plate or flange nail can be used in a similar manner

3 The Nicola procedure may be effectively used

4 A Rush nail (Fig. 194) driven down through the humeral head has been used effectively particularly in those instances in which little bony substance remained in the cartilagenous cap.

5 Multiple screws have been used but fixation was not too secure and some form of external support had to be used for 6 weeks or so

6 When the humeral head is badly shattered and cannot be reconstructed it is best to resect the shattered pieces and attach the rotator cuff to the proximal humeral shaft The methods used by Jones and by McLaughlin and Asherman are satisfactory

An alternative would be the use of some form of prosthesis but our experience in this respect has been meager

Fusion of the shoulder is rarely indicated for this type of injury

INJURIES TO THE ROTATOR CUFF

Tears of the rotator cuff may be caused by a specific injury such as a fall or a sudden lifting strain. They may also result from attritional changes, without any specific injury An injury on the other hand may extend or increase a pre-existing rent in the cuff DePalma and also McLaughlin and Asherman have catalogued these findings

Codman was one of the first surgeons to investigate rotator-cuff injuries thoroughly

DIAGNOSIS

A careful study should be made of the following list which covers the eighteen significant factors in the diagnosis of a ruptured supraspinatus tendon or rotator cuff This list is from Codman s book *The Shoulder*

Certain conditions symptoms and signs which indicate complete rupture of the supraspinatus tendon and which should be present within twenty four hours after the accident:

1 Occupation—Labor
2 Age—Over 40
3 No symptoms in shoulder prior to accident
4 Adequate injury—usually a fall.
5 Immediate sharp brief pain
6 Severe pain on following night.
7 Loss of power in elevation of the arm
8 Negative x ray
9 Little if any restriction when stooping
10 Faulty scapulo-humeral rhythm
11 A tender point
12. A sulcus and
13 An eminence
14 At the insertion of the supraspinatus
15 Which cause a jog
16 A wince and
17 Soft crepitus as the tuberosity
18 Disappears under the acromion when the arm is elevated and usually also as it reappears during the descent of the arm

In addition to the history and physical findings arthrograms may give added information regarding the presence or extent of rotator cuff tears

Treatment

The over all treatment of rotator cuff tears by the Fracture Service at the Massachusetts General Hospital is conservative Specific therapy depends upon the extent of the tear and the age of the patient

In our opinion most patients with a partial or incomplete rotator cuff tear will do very well on conservative treatment This would consist of initial rest to the shoulder with a sling followed by a program of graduated exercises. Inman Saunders and Abbott have demonstrated that a partial cuff tear or a tear involving for instance only the supraspinatus tendinous portion of the cuff tendon does not eliminate abduction of the shoulder They demonstrate that the teres minor infraspinatus and subscapularis muscles are the chief depressors of the humeral head which allow the deltoid muscle to elevate the shoulder De Palma also found varying degrees of rotator cuff tendon tears at autopsy in patients who had not complained of shoulder disability

Symptoms and disability from a partial rotator cuff tear may be due more to impingement of the thickened edges of the torn tendon under the acromion than to the rupture or tear per se We have had very good results in selected cases by performing an acromioplasty and smoothing down the rough furrows of the rotator tendon, thus giving the shoulder mechanism more clearance under the acromial roof and less impingement of tissues

When however by clinical findings or injection methods a complete avulsion of the rotator cuff attachment to the humeral head is demonstrated which would include the supraspinatus infraspinatus and varying portions of the teres minor or subscapularis tendon attachments disability of the shoulder will result unless the tendons are effectively repaired to the humeral head or tuberosities In these instances there is loss of "depressor" power to the humeral head or a stabilizing effect to allow the deltoid muscle to function

In youth and adulthood the blood supply to the rotator cuff is adequate and satisfactory repair can be anticipated The technique of repair has been excellently demonstrated by Lawrence Jones and by McLaughlin and Asherman The tendon should if possible be reattached to viable bone even if some portion of the humeral head has to be sacrificed to obtain a satisfactory bed Postoperatively the shoulder is supported in a plaster spica with the arm in 40 degrees of abduction and 40 degrees of forward flexion (position "salute") It is safe to protect the repair in this position for 6 to 8 weeks before allowing shoulder motion

When a complete rotator cuff avulsion occurs in the elderly patient (60 years and older) we are faced with a different problem In this age group the blood supply to the rotator cuff tendons is as a rule insufficient to provide healing Our experience in surgical repair of severe cuff avulsion in the elderly has been poor Because of insufficient blood supply the cuff tendon does not heal, and the tendon in a relatively short time pulls off the humeral head leaving the patient with his previous disability

SURGICAL APPROACHES TO THE SHOULDER JOINT

All aspects of the shoulder can be approached by some portion of the "utility" incision (Fig 195 A and B) This incision follows the attachment of the deltoid muscle on the outer third of the clavicle around the acromion and along the spine of the scapula

The incision should be placed so that it can be enlarged in line with the deltoid attachment anteriorly or posteriorly Adequate exposure can thus be obtained Deltoid muscle-splitting incisions should be used only when a limited exposure is needed. Such incisions should be confined

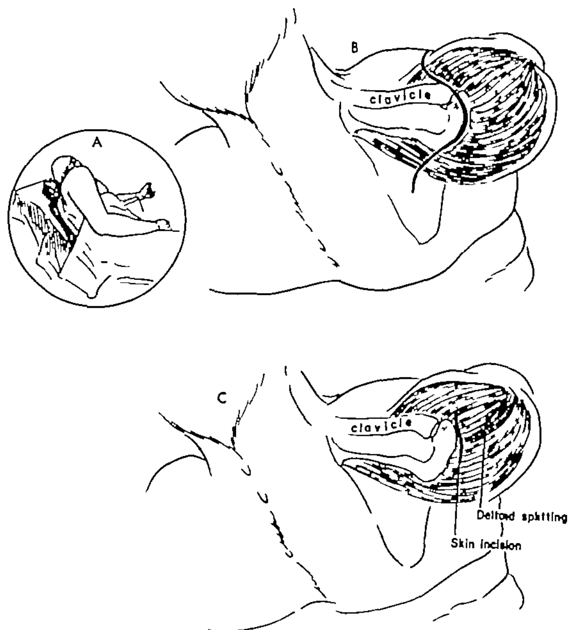


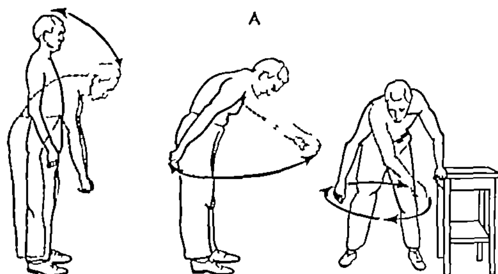
Fig 195 —Surgical approaches to the shoulder A, position of the patient, shoulder pointing upward B the "utility" incision or deltoid "turn-down" exposure C muscle-splitting incision used in upper portion of the deltoid

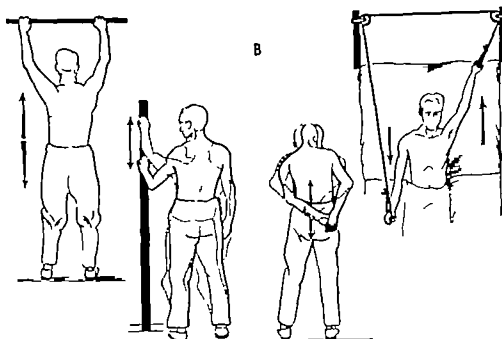
to the upper third of the deltoid muscle

Anterior and Superior Shoulder Approach —This the most commonly used approach to the shoulder has been described in detail on page 269 (Bankart procedure) If further exposure is needed the incision is extended posteriorly along the rim of the acromion An acromioplasty is frequently indicated for more adequate exposure of the humeral head or rotator-cuff tendons

Posterior Shoulder Approach —This can be a local approach or it may be combined with the anterior approach A number of descriptions have been given independently for approach to the posterior aspect of the shoulder

As in the anterior approach the skin incision should follow the deltoid attachment but may be tapered off inferiorly for dependent exposure The deltoid muscle is released from the spine of the scapula and turned outward It is not necessary to de-





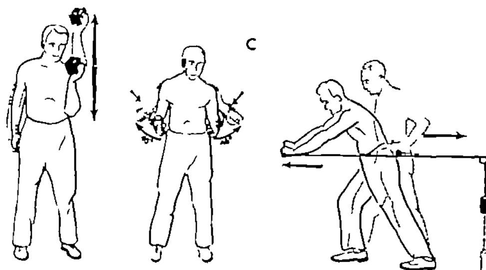


Fig 196 —Exercises for the shoulder A, early pendulum exercises B stretching exercises C resistive exercises

tach the entire posterior expansion of the deltoid muscle. Reflecting two thirds of the muscle mass is usually sufficient this uncovers the posterior rotator-cuff muscles and attachments Care must be taken not to injure the circumflex (axillary) nerve which emits posteriorly from the quadrilateral space or the suprascapular nerve which courses around the suprascapular notch The rotator cuff is divided at its point of insertion to the greater tuberosity of the humeral head thus exposing the posterior capsule It will be noted that the external rotators do not adhere to the capsule as extensively as does the subscapularis tendon anteriorly The capsule can be opened for inspection of the shoulder joint The most direct approach to the glenoid fossa and the glenoid neck is from the posterior approach

DELTOID-MUSCLE SPLITTING INCISIONS —Deltoid muscle-splitting incisions (Fig 195 *A* and *C*) may be used for limited exposures of the head or cuff as for instance in removing calcium from the rotator cuff or in making a biopsy of the humeral head However to split the deltoid muscle anteriorly or laterally for more than 1½ or 2 inches may endanger the axillary nerve

1 A 1½ inch saber incision is made horizontally over the greater curvature of the shoulder just lateral to the acromion This incision should follow a skin crease if possible to produce hairline healing. Vertical incisions in this area tend to thicken or spread.

2 The deltoid muscle is identified and split vertically in line with its fibers for a distance of 1½–2 inches from the acromion This will expose the subdeltoid bursa which may be opened exposing the rotator cuff tendon.

3 By rotating the humeral head in external and internal rotation a good view of the entire rotator-cuff attachment is obtained

SHOULDER EXERCISES

Exercises for the shoulder (Fig. 196) may be divided into three general types early pendulum stretching and resistive exercises

1 The earliest shoulder exercises may best be rhythmic pendulum exercises (Fig 196 *A*) These should be performed with minimum muscle action but they must be carried out in a position of moderate forward flexion of the body so as to eliminate impingement of the humeral head on the undersurface of the acromion

2. The second group of shoulder exercises may be called the "stretching" exercises (Fig 196 *B*) These should be carried out gently and frequently so as to gradually regain shoulder motion without producing reaction in the tissues stretched

3 The third group is the strengthening or active "resistive" exercises (Fig 196 *C*) If instituted too early these may produce pain and irritation of the shoulder mechanism Maximum benefit is obtained from the resistive group if time is first allowed to regain a useful degree of motion for active exercises

Exercises to avoid are repetitious forceful shoulder motions carried out at shoulder level or at 90 degrees of abduction In this position the short rotator tendons and protective subacromial bursal tissues are impinged against the undersurface of the acromion

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Humeral Shaft Fractures

THE FEATURES WHICH give the humerus its uniqueness among the long bones as a site of fractures are primarily teleological. During the process of evolution the conversion of the arm from a weight bearing extremity to a prehensile and highly functional limb resulted in the sacrifice of stability in the proximal joint of the arm and the substitution of finely co-ordinated muscular action through the medium of balanced lever arms Because of the all important end organ the hand the structures traversing the region of the humerus have singular significance since the rehabilitation of an injured upper extremity plays a vital role in restoring the function of the individual as a whole

ANATOMICAL CONSIDERATIONS

The shaft of the humerus is cylindrical in its upper half and gradually broadens and flattens in its distal portion The fusiform anterior or upper-arm muscle is the biceps brachii beneath which lies in its upper portion the point of insertion of the coracobrachialis muscle and in its lower portion the place of origin of the broad brachialis muscle (Fig 197) Flexion and fixation of the elbow and shoulder are the coordinated function of these muscles Along the medial aspect of the humerus courses the main neurovascular bundle with the brachial artery and vein and the median musculocutaneous and ulnar nerves These lie in the anterior compartment which is divided from the posterior compartment by the medial and lateral intermuscular septae The primary posterior landmark is the fusiform triceps the medial and lateral heads of which have their origin in the posterior shaft. Between these heads next to bone lies the radial nerve which travels obliquely downward and lateralward as it passes from the posterior axilla to the anterolateral epicondylar region. The triangular deltoid muscle caps the shoulder joint its anterior lateral, and posterior elements converge into a single tendon which inserts into the deltoid tuberosity which is easily palpable on the lateral midshaft of the humerus The deltoid muscle flexes abducts or extends the upper arm The broad fan-shaped pectoralis major muscle which forms the anterior axillary border originates in the upper anterior chest wall and converges into a flat tendon which inserts into the lateral lip of the bicipital groove of the humerus (see Fig 198 A and C) This muscle acts conjointly with other muscles in depressing the elevated arm to the side of the chest and as a strong adductor and internal rotator of the upper arm

Beneath the body of the deltoid muscle the muscles of the rotator cuff surround the

humeral head (See Chapter 17, on Shoulder Girdle Injuries) The essential elements in humeral shaft fracture analysis are the abduction action of the supraspinatus and deltoid muscles the internal rotation func

reveal an area of tenderness which has been obscured by the more severe pain of the obvious injury The underlying disability may be one of soft tissue only but x ray confirmation is mandatory where doubt ex

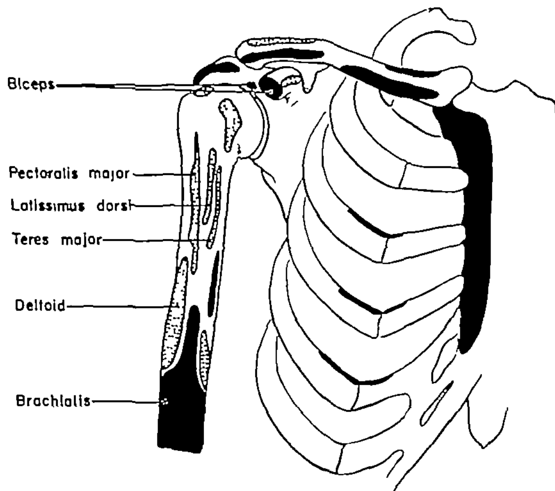


Fig 197 —Important muscle attachments to be considered in humeral shaft fractures

tion of the subscapularis muscle and the adduction action of the pectoralis major

PHYSICAL EXAMINATION

The critical examiner must be alert not only for obvious evidence of a humeral shaft fracture of swelling, pain and deformity but also for possible secondary or associated trauma. Radial nerve injury carpal and metacarpal fractures forearm and elbow disabilities as well as shoulder girdle and vascular problems have all been reported as complicating features A methodical palpation and a testing of the joint functions of the entire upper extremity may

ists A simple test of nerve function helps to complete the evaluation A comprehensive and thoughtful initial examination often saves the examiner future embarrassment, as well as serving as base line evidence in the evaluation of latent or progressive nerve or vascular injury

ETIOLOGY AND TYPES OF FRACTURES

A direct force applied to the humeral shaft most commonly results in a transverse or comminuted fracture Segmental fractures may exist and care must be exercised in assuring that the x ray films give

adequate visualization of the entire humerus The more severe the blow the greater the possibility of a comminuted or an open fracture An indirect violence such as a fall on the outstretched hand or on the elbow may produce spiral and/or oblique shaft fractures with secondary fractures—e g radial navicular clavicular etc A forceful muscular action such as gymnastics or throwing a baseball frequently results in a spiral fracture The surgeon must always be wary of a minor injury that results in a fracture since a pathological lesion—be it a benign bone cyst or a metastasis—is not uncommon in this area.

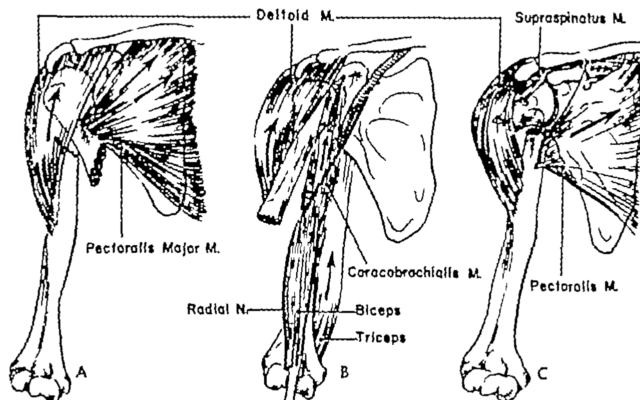


Fig 198 —Characteristic deformities of typical humerus fractures A, adduction of proximal fragment with fracture between pectoralis major and deltoid insertions B abduction of proximal fragment with fracture distal to deltoid attachment C abduction and rotation of proximal fragment with fracture between rotator cuff and pectoralis major insertion

TREATMENT

General Considerations

Conservative management of the humeral shaft fracture is employed whenever possible. In washing away the initial hematoma the interfering surgeon all too frequently removes the metabolites that are necessary for fracture healing and clears the way to potential nonunion The humerus is a notorious "bone of contention" from this aspect since open operations are among the most frequent causes of failure in bone healing.

Based on an analysis of the mechanism of injury physical examination and x ray findings and the muscle forces producing the deformity (Fig 198) a partial decision can be made as to the management of the fracture Also to be considered are the age of the patient and the dominance of the involved extremity A moderate deformity of a left humeral fracture in an elderly right handed woman may be more readily acceptable than the same fracture in the dominant arm of a young family-supporting man doing heavy labor Ambulatory

versus sedentary methods of treatment must be taken into consideration Can the individual tolerate the discomfort of the first few days in a hanging cast? Can he be taught the principle of this form of treat ment and will he co-operate? Are there medical contraindications to anesthesia? Will bed rest be tolerated? Are there other associated injuries? All factors must be weighed for in the final analysis the treat ment should conform to sound principles duction of the fracture Displacement of the fragments may be minimal in which case the position may be accepted without specific manipulation or in anticipation of slight reduction by the traction from the cast However whenever there is marked deformity (shortening rotation or angu lation) reduction under anesthesia or in travenous analgesia is mandatory prior to the application of the cast The hanging cast may contribute substantially to the

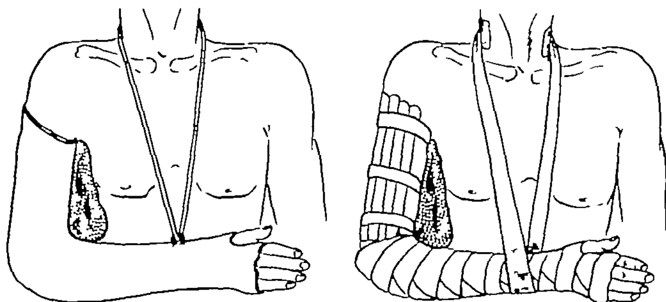


Fig 199 —Left hanging cast Useful where alignment of the fracture can be maintained *with partial immobilization and by following the principle of the "vertical vector" Note axillary* wedge (See also Fig. 200) Right coaptation splint.

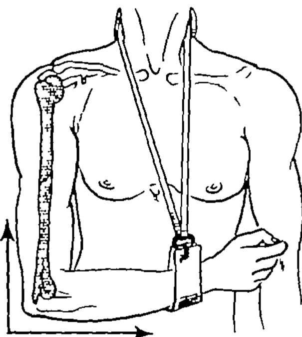
and yet be suited to the individual insofar as possible

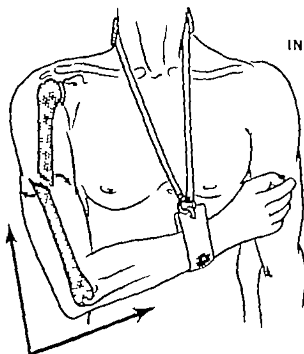
Hanging Cast

In practice the hanging cast (Fig 199 *left*) is one of the most widely accepted and successful methods used for the treatment of spiral fractures of the middle or lower portions of the shaft Yet this method is fraught with potential danger In principle it consists of partial immobilization of the fracture by means of a long arm cast applied so as to produce moderate extrinsic traction aimed at relaxing the musculature and aiding in the reduction and alignment of the fractured elements

The first step in management is the re- length of the upper arm and to the align ment of the fragments but its purpose is primarily one of maintenance of rather than producer of reduction If the cast weight is excessive distraction occurs and delayed union may result If the forearm support is incorrectly placed or the upper arm is in a position of abduction due to obesity angulation deformity occurs (Fig 200)

The cast is applied from axilla to wrist with the elbow in a right angle position and the forearm in neutral rotation A powdered axillary pad prevents irritation and a cor rectly placed collar and cuff (Fig. 200) predisposes axial alignment of the frac ture In the early stage of treatment fre





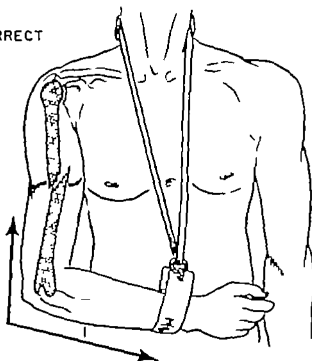


Fig 200.—Correct placement of forearm support is imperative in maintaining alignment.

quent x ray checking of the position of the fracture is essential since the resilience of the initial callus may allow for adjustment of the reduction

The hanging-cast method is ideal in the comminuted fracture of the lower two thirds of the humerus and in long spiral oblique fractures In fact this method is best adapted to those fractures which have a broad exposure of the fractured surfaces It is less well adapted to the transverse shaft fracture or to fractures of the proximal third of the shaft where angulation deformities are prone to occur

A drawback of the hanging cast is the requirement that the vertical vector be maintained Consequently a co-operative patient who is willing initially to sleep in a semireclining position without support beneath the elbow is a prerequisite A wedge may need to be added to the medial aspect of the elbow in the obese individual where angulation over redundant tissues frequently occurs (see Fig. 199) Shoulder exercises may be started early using gentle pendulum motions which swing the cast away from the body (see p 287 Fig 196 *A*)

The hanging-cast method has been proved in practice and is widely applicable and adaptable to the majority of humeral shaft fractures except those in the upper third portion

Coaptation Splint

Another acceptable method consists of a coaptation splint (Fig 199 *B*) or plaster splint, to the arm and a collar and cuff These are applied secondarily after reduction has been achieved or primarily in instances of minimal displacement of the fractured elements and where the vertical weight of the arm is sufficient to maintain position The coaptation splint is often used in children where the periosteal tube acts as a firm internal aligning element and where moderate deformities are acceptable in view of the extensive remodeling possible in the child *The method is probably* best adapted for use during convalescence as a transition method after the more radical splinting has been removed and before allowing the patient complete freedom

Plaster Spica

In some instances the use of a spica is indicated as in children who cannot co-operate in the use of a hanging cast. The plaster spica is cumbersome and often difficult to apply and consequently it is a less adaptable form of treatment. When used however it is essential that the iliac crests be included in the spica and that care be exercised in molding to the bodily contours or else the sheer weight and awkwardness of the cast may cause stresses and strains at the fracture site detrimental to healing and maintenance of reduction

The plaster spica is most strongly indicated in the early healing stage of the unstable fracture such as after a period of traction and it is replaced by a simpler form of treatment as soon as the fracture elements show evidence of maintaining reduction It is also indicated in those cases where delayed union or nonunion appears imminent and more complete immobilization is desired Its purpose can be defeated however unless care is taken to assure form fit The plaster spica is contraindicated in the obese in warm weather when skin hygiene is difficult and in the elderly patient, where the added burden may be detrimental.

Sling and Swathe

Sometimes the usual methods of maintaining reduction by external means prove unsatisfactory This is particularly true in proximal shaft fractures The adduction force of the pectoralis major muscle notoriously prevents reduction and where abduction or neutral positions leave an unacceptable fracture relationship a position of adduction across the chest and immobilization with a sling and swathe may bring *about an acceptable position*

Skeletal Traction

Only rarely is the use of traction indicated in the treatment of the humeral shaft fracture Skeletal traction is a difficult method of treatment, requiring close supervision by the doctor as well as a co-operative patient. The necessary apparatus whether for ambulatory or recumbent use is complex and has the added disadvantage of possibly producing a distraction leading to nonunion or even damage to neurovascular elements Skeletal traction may be effectively used where an open fracture exists and observation and dressing changes are necessary and where comminution and shortening have occurred It is indicated most strongly where treatment in recumbency is necessary because other injuries exist

Probably the simplest method of applying skeletal traction is through the olecranon, with suspension of the forearm and hand (Figs 222 and 201) Countertraction by the patient s body is obtained by tilting the bed. Checking the circulation in the hand and frequently reminding the patient to exercise the fingers are adjuncts of treatment by traction.

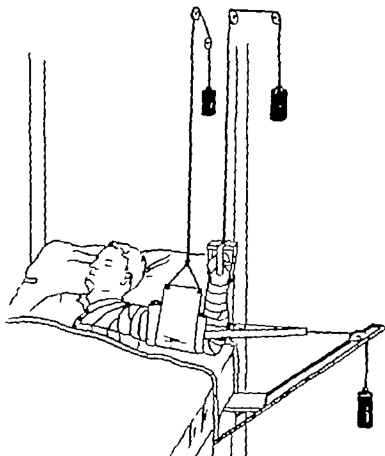


Fig 201 —Axial traction in recumbency skin-adhesive technique (See also Fig 222.) Skeletal technique may also be used

Open Reduction

Before deciding to perform an open reduction of a humeral shaft fracture the surgeon must carefully consider all the factors involved Open reduction has the advantage of obtaining anatomical alignment with internal fixation It may allow early exercising of the elbow and shoulder and the period of discomfort is shortened This form of reduction is indicated in those situations where interposition of soft parts prevents adequate reduction In potential

nonunion or delayed union where actual nonunion exists and where there are se vere associated neurological or circulatory problems *It is important to remember that* where firm internal fixation has been obtained both the doctor and the patient may have a false sense of security and it is therefore essential that some form of ex ternal protection be maintained until there is x ray evidence of progressing union

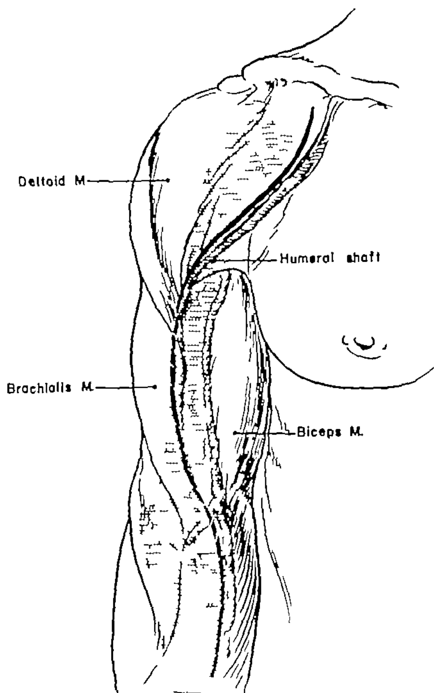


Fig 202 *—Utility incision for exposure of whole or part of humeral shaft*

Exposure of the humeral shaft is readily performed through the class terior approaches The proximal sh readily available through the deltoi toral approach (see p 269 Fig whereas the middle and the distal may be visualized by medial displace of the biceps muscle and direct in through the originating point of the b alis muscle (Figs 202 and 203) Th

ter exposure avoids the radial nerve but care must be taken so that the nerve is not traumatized by heavy retraction.

Numerous methods of internal fixation are available and each has its preferred application Multiple screws adapt well to maintaining length and alignment but frequently they are *difficult to introduce* and they may fail to stabilize rotation and may keep fracture ends apart (Fig 207 *B*) When used in conjunction with Parham bands the medullary nail effectively

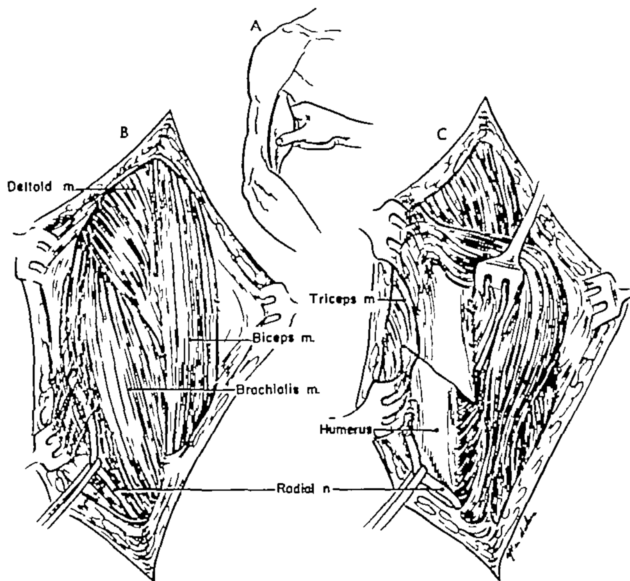


Fig 203 —A, displacing biceps muscle to identify brachialis muscle directly over shaft. B and C, exposure of shaft and radial nerve in direct contact with shaft. (Adapted from Banks S W and Laufman, H *An Atlas of Surgical Exposures of the Extremities* [Philadelphia W B Saunders Company 1953])

the long spiral-oblique fracture (Fig. 204) whereas plate and screws best fix the transverse fracture (Fig. 205) A combination of both methods may stabilize the comminuted fracture with a butterfly fragment. Intramedullary nails (Fig 206) are useful in segmental and transverse fractures for controls the markedly comminuted fracture but usually the fracture requires some additional external support A bone graft is *commonly indicated in nonunion* and the fibula (Fig 207 C) or tibia serves as an acceptable source for the graft Such a graft does well when firmly applied to a



Fig 204 —Open reduction elected on long spiral-oblique fracture because of forced confinement to bed for secondary injuries Postoperative support with sling and swathe Good functional use in 3 months

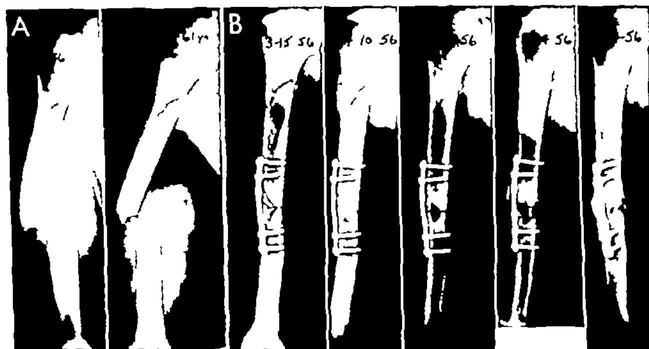


Fig 205 —A, segmental fracture (proximal and middle thirds of shaft) Unable to maintain a closed reduction B open reduction with plate and screw fixation and without grafting Note delayed union at midshaft fracture and early union in unexposed proximal-shaft fracture

raw area of superficially denuded cortical bone and with cancellous onlay grafts placed opposite the fracture site In those instances where osteoporotic cortical bone is unable to support screws plates or nail fixation it may be necessary to telescope the fragments of the fracture holding them with circumferential wires or Parham bands and to accept shortening of the humerus (see Figs 54 and 55 *A* and *B*) Variations and combinations of the foregoing techniques may be necessary in unusual instances



Fig 206 —Shaft fracture in an unco-operative 65-year-old male unreliable fixation A, transverse fracture of middle third of humerus B poor maintenance of reduction with posterior plaster splint and cravat C 2 month postinsertion of Rush nails by "blind technique Full shoulder and elbow motion. Clinically healed

COMPLICATIONS

Complications in the healing of humeral shaft fractures are common and include some of the most difficult problems in the field of trauma. Nonunion of these fractures is a major tragedy and requires the maximum skill and judgment of the surgeon to overcome Radial nerve and vascular injuries are likewise common and similarly require close supervision in order to be corrected Of lesser importance is the possible ultimate limitation of motion in the shoulder and/or elbow joints Above all it is of utmost importance for the surgeon to be aware of the potential dangers and to practice prevention

Delayed union occurs most frequently in the transverse fracture where only a small area of bone surface is involved and in the fracture where open surgery has been performed In the latter situation the initial hematoma with its healing elements and the potential external callus are lost. Reconstruction of the trabecular continuity and revascularization may be hampered by the interposition of soft parts and where suspected this condition must receive early consideration in surgery Ultimate union may only be achieved by supplemental cancellous bone grafting taking care to keep to a minimum any disturbance of the healing process that may already be present. The frank nonunion is often attributable to distraction of the fracture elements (Fig 207 *A*) by the ardent use of a heavy hanging cast or the overpull by the olecranon wire but it is also traceable to mobilization before adequate healing time has been allowed

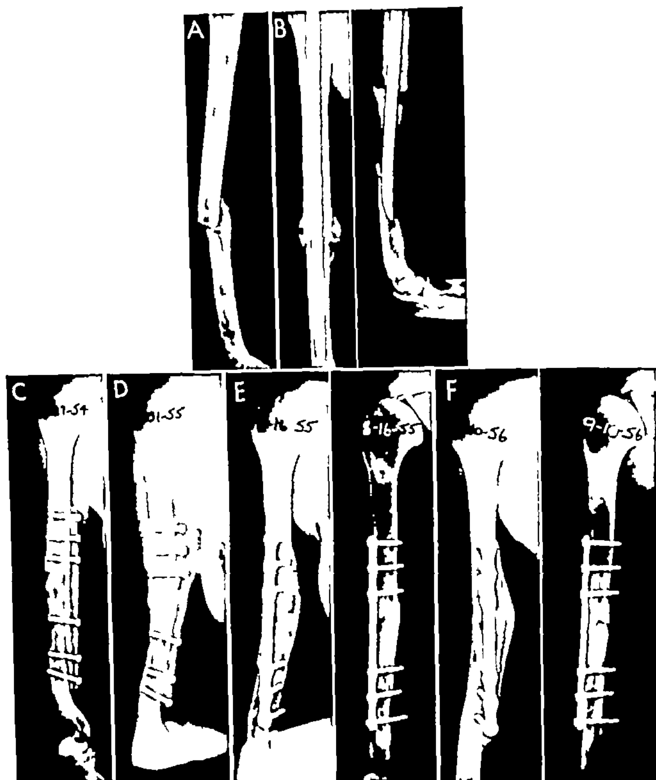


Fig 207 —Transverse fracture Delayed union due to distraction and inadequate periods of immobilization Initial olecranon wire traction for 3 weeks followed by 6 weeks with a hanging cast A, 9 weeks postfracture Distraction delayed union B intramedullary nail fails to correct distraction Subsequent treatments included spica iliac grafts fibular grafts and screw fixation C 2 years postfracture with nonunion. Open reduction with screw fixation of full-thickness fibular graft plus iliac grafts D nonunion with fracture through fibular graft 8 months postoperatively E operation removal of screws fixation with Vitallium plate osteoperiosteal tibial grafts F ultimate union after 4 years and 7 operations

Associated radial nerve injury is variously reported as occurring in from 5 to 10 per cent of all cases of humeral shaft fractures In those instances where complete loss of function of the nerve is believed to be due to severance immediate surgical treatment is indicated However where palsy develops several weeks after the initial trauma and treatment, it must be suspected that the callus is the most likely causative agent Close observation as to the progression or regression of signs will determine whether exploration, decompression repair or transplantation of the nerve is warranted. When it is believed that contusion or concussion of the nerve is the basis of the neuropathy the surgeon may reasonably wait for several weeks for early evidence of returning function A useful adjunct in evaluation is an electromyographic analysis of the status of the reaction of degeneration. However in most instances of neuropathy spontaneous gradual recovery of the nerve is the rule

Vascular damage may occasionally have severe complications as when the brachial artery or vein is lacerated or severed. Early recognition and treatment by ligation or anastomosis are then necessary

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19 

Dislocations and Fractures of the Elbow

DISLOCATIONS OF THE ELBOW

DISLOCATIONS OCCUR more frequently in the elbow than in any other joint in the body with the exception of the shoulder Like all dislocations elbow dislocations should be reduced as soon after injury as possible in order to relieve pain and avoid circulatory changes soft tissue tension and swelling

The following types of dislocations may occur at the elbow joint (1) posterior (2) lateral—outward or inward (3) anterior and (4) radial head—forward backward and lateral. The posterior type is by far the most common occurring at any age but more frequently in children and adolescents The forearm bones are displaced backward backward and outward or backward and inward

Pure lateral dislocations are quite rare and are usually associated with fractures of either the internal or external humeral condyles Forward or anterior dislocations are extremely rare and are nearly always associated with fracture of the olecranon but they can occur without any associated fracture

Radial head dislocations occur most frequently in young children but they may also be seen in adults usually as a complication of Monteggia fractures Radial head dislocations occur most frequently in young children but they may also be seen in adults—usually as a complication of Monteggia fractures In children they are believed to be the result of sudden traction on the forearm while in adults they are thought to result from severe pronation injuries

POSTERIOR OR BACKWARD DISLOCATION OF ELBOW

MECHANISM —Posterior dislocation of the elbow (Fig 209) usually results from a fall on the outstretched arm which causes the elbow to be hyperextended and abducted. As the force of the body weight is applied to the arm in this position the inner portion of the joint capsule is put under tremendous strain and gives way resulting in a subsequent tear across the entire anterior capsule and driving the humerus downward through the torn capsule in front of the coronoid process The latter being forced upward and backward finally comes to rest behind the lower end of the humerus

DIAGNOSIS —The deformity resulting from a posterior dislocation of the elbow

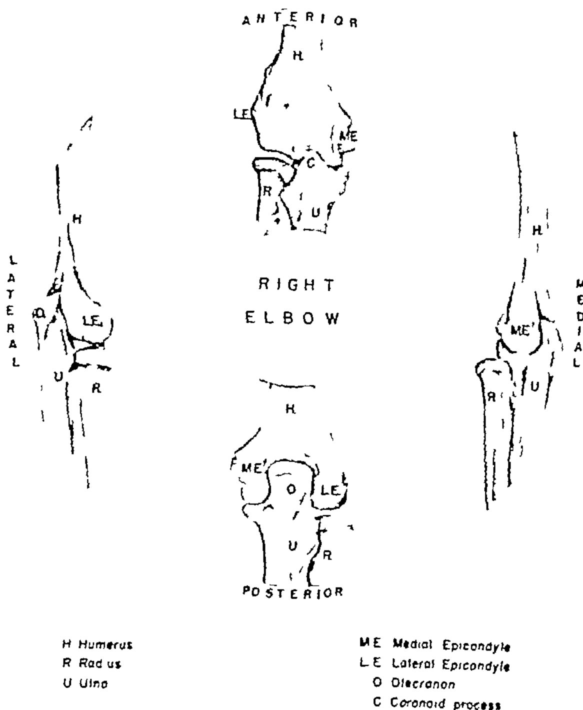


Fig 208 —Anatomy of the elbow joint

is similar to that of a supracondylar fracture and in the presence of marked swelling, the diagnosis is often difficult to establish clinically However there are certain differences which distinguish the two conditions such as (1) the degree of mobility (2) the relationship of the olecranon to the epicondyles and (3) the position of the head of the radius in relation to the external condyle and olecranon In typical posterior dislocations of the elbow there is less mobility of the affected parts as a rule than in supracondylar fractures the olecranon is found above and behind the line joining the epicondyles and the head of the radius is found to be posterior to the external condyle and lateral to the displaced olecranon This distortion of the

normal anatomical relationship of the bony landmarks about the elbow helps in establishing the correct diagnosis

TREATMENT —Under adequate regional



Fig 209 —Posterior dislocation of the elbow

or general anesthesia the dislocation is reduced by manipulation and traction The alignment of the humerus and forearm is first corrected by manipulation and then traction is made on the forearm in the position in which it is resting There is no need for completely extending or hyperextending the elbow while traction is being applied—in fact such movement is contraindicated and dangerous because it may inflict additional damage by the stretching of tissues over the front of the joint

An assistant holds the upper arm while the operator grasps the upper end of the dislocated forearm with one hand and corrects any lateral displacement by lateral pressure Then with his other hand which is grasping the patient s wrist he applies sufficient traction on the forearm to draw it forward on the humerus and allow easy and unrestricted flexion If undue resistance is encountered in flexing the elbow force should not be used because reduction has not been accomplished Instead the entire maneuver should be repeated

POSTREDUCTION CARE.—The elbow is maintained in acute flexion or in as much flexion as swelling and circulation will safely allow by means of a collar and cuff sling (Fig 210) Check x ray films are then made to verify satisfactory reduction and reveal any associated fractures As an additional safeguard against possible redislocation a posterior plaster-of paris slab is applied to the flexed arm Shoulder and finger exercises are begun at once

Immobilization of the elbow is continued for 3 weeks and then followed first by active movements of the joint within the range of a right angle and later when all support is discarded by a complete range of active motion *Passive motion forced motion and massage are unwise and may be harmful* since they may encourage the formation of myositis ossificans

While posterior dislocations of the elbow occur rather commonly they should be looked on as a serious condition for quite frequently limitation of extension may result or it may take a long time for extension to return completely

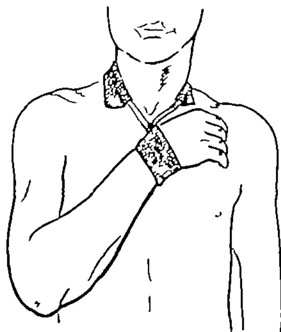


Fig 210 —Immobilization by a collar and cuff sling following reduction of dislocated elbow

OLD UNREDUCED POSTERIOR DISLOCATION OF ELBOW —It may be possible to reduce a posterior dislocation of the elbow by the closed method of manipulation and

traction if the accident occurred within a period of 3 weeks but if a longer time has elapsed since the accident closed reduc tion will necessarily be too traumatic—if not impossible—and open reduction is in dicated The operative procedure of choice is the one which will allow careful preser vation of the articulating joint surfaces and a reduction of the dislocation with a minimum of trauma. A simple operative method which has been successful in ac complishing these two purposes was presented in the Journal of Bone and Joint Surgery (14 127 1932)

If the old unreduced dislocation is associated with fractures in the same joint or with injury to the articular surfaces then a choice must be made between a "sham reduction" arthroplasty or a fusion. Com plete excision of the elbow joint, as an operative procedure has not proved suffi ciently successful at the Massachusetts General Hospital for the staff to recommend it as a method of choice

Lateral Dislocation of Elbow

Pure lateral dislocations of the elbow without associated fractures are very rare (Fig. 211) They result from complete rupture of the joint capsule and both lateral ligaments The dislocation may be inward or outward The dislocated joint is as a rule extremely unstable and readily mov able so that all that is needed to reduce the dislocation is lateral pressure on the dis placed side If additional help is necessary a slight rocking movement of the forearm may be used It is not unusual to find that the joint space between the olecranon and the lower end of the humerus is greatly widened following reduction owing to the laxity of the torn lateral ligaments and it sometimes is advisable to support the plaster that splints the humerus and forearm bones from a shoulder cap similar to an upper arm prosthesis so that gravity and the weight of the cast will not increase the amount of articular separation

After 1 month of immobilization acti e motion is begun The end results of this type of dislocation have been exceptionally good



Fig 211 —Anteroposterior and lateral views of lateral dislocation of the elbow without fracture

Anterior Dislocation of Elbow

Anterior dislocations of the elbow with out any associated fracture are extremely

rare—so rare that they may be looked on as a curiosity

In the literature on this subject it is stated that forward dislocations without fracture of the olecranon may occur in three ways

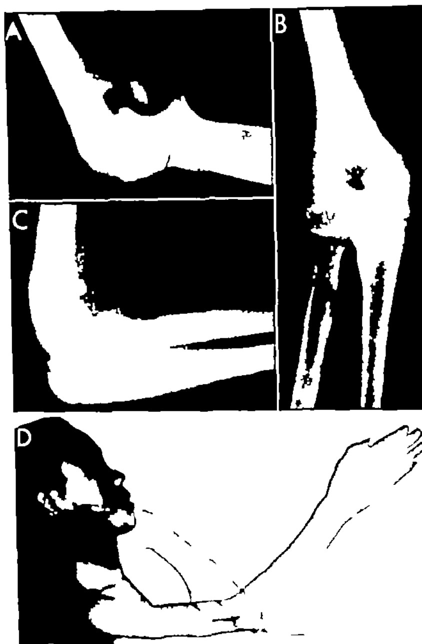


Fig 212 —A, anteroposterior and B lateral views of anterior dislocation of the elbow with out fracture (5 weeks duration) C reduction D function 6 months after operation

(1) by forced flexion of the forearm (2) by fixing the upper arm and turning the forearm around the axis of the upper arm and (3) by hypertension of the forearm A fall on the flexed elbow is considered by the majority of authorities to be the most likely cause of this injury

The second method of producing an anterior dislocation (Fig 212) is illustrated by the history of a boy who weeks previously had suffered an injury while on a high rope swing As he swung through the air standing on the seat of the swing the rope on the left side suddenly gave way causing his entire body to fall heavily and the weight to drag on his right arm and hand as he clung to the rope on the right side In addition to causing tremendous traction on his right arm the mo-

mentum of his body as it turned around in the air produced a twisting or torsion force on his elbow which resulted in a lateral dislocation that was quickly converted into an anterior dislocation. The mechanism of this dislocation was apparent at the time of open reduction, when it was found that the only possible way to obtain reduction was to reverse the procedure of dislocation by drawing the forearm bones from in front of the humerus out to the side in the position of a lateral dislocation and then to reduce them in proper alignment beneath the articular surface of the humerus (Fig 212 C) In this case no evidence of fracture was seen either by x ray examination or at operation, and the olecranon was intact.

It is a mis-statement of fact therefore when certain textbooks on fractures state that anterior dislocations of both forearm bones cannot possibly take place at the elbow without a fracture of the olecranon process of the ulna.

Closed reduction of these anterior dislocations may be *very difficult or impossible* but when attempted it should follow the same rule of reversing the mechanism that produced the dislocation

Dislocation of Head of *Radius*

Dislocation of the head of the radius alone occurs rather frequently in young children *but only rarely in adults* When it occurs in children it is often termed a "subluxation" and it may spontaneously reduce itself with attempted elbow motion

The mechanism of this type of injury is poorly understood one theory being that in the case of young children the head of the radius is pulled through the orbicular ligament by traction on the wrist or forearm thus freeing the head while the pull of the biceps tendon displaces it anteriorly A second theory explains the dislocation as being the result of a "pronation injury"

Diagnosis —The diagnosis of dislocation of the head of the radius is made by noting the following signs

1 The forearm is held in pronation and slight flexion

2. There is limited flexion and supination at the elbow

3 The head of the radius is palpable in an abnormal position usually in the soft parts in front of its normal location.

Treatment —Reduction of the dislocation is accomplished by extending the forearm, slightly adducting it, and applying traction Following this digital pressure is made over the radial head as the forearm is supinated After full supination is obtained, the elbow is flexed and the reduction should be complete But should supination and flexion remain limited after the manipulation, reduction is not complete and the maneuver must be repeated

Immobilization of the elbow joint in acute flexion and full supination should be employed for 2–3 weeks and then a sling may be used

In those cases where reduction cannot be maintained operation is indicated and after the radial head is replaced the annular ligament should be repaired and sutured about the head

In long-standing dislocation of the head of the radius it has been suggested that, after open reduction a new annular ligament be created out of fascia lata and that this ligament be placed about the radial neck and also be attached or tied to the ulna in order to avoid recurrence of the dislocation This operation has been used rarely at the Fracture Clinic of the Massachusetts General Hospital and with very limited success In an old dislocation of the radial head it is believed wiser either to accept the situation as it stands or in the case of an adult to do an excision of the radial head

FRACTURE DISLOCATIONS OF THE ELBOW

Unfortunately many dislocations of the elbow joint are complicated by associated fractures as noted in Table 12. When such fractures are present a wise rule to follow is to treat the dislocation first as though

TABLE 12.—FRACTURES COMMONLY ASSOCIATED WITH ELBOW DISLOCATIONS

DISLOCATIONS	ASSOCIATED FRACTURE
Posterior	Coronoid process of ulna Head of radius External condyle of humerus (very rare)
Lateral	Internal epicondyle of humerus External condyle of humerus
Anterior	Olecranon
Radial head	Ulna (middle or upper third) (Monteggia fracture)

the fracture was not present and then after reduction of the dislocation treat the fracture as if the dislocation had never existed

POSTERIOR DISLOCATION OF ELBOW WITH FRACTURE OF CORONOID PROCESS

This is the commonest form of complication in posterior dislocations of the elbow and is actually a chip fracture of the tip of the coronoid process of the ulna resulting from the tearing away of the insertion of the brachialis anticus tendon when the forearm bones are forced backward below and behind the humerus The fracture is usually of no great importance and nearly always unites especially if the joint is immobilized in flexion with a collar and cuff sling Should the broken fragment or fragments comprise a large portion of the coronoid process then more rigid fixation is advisable and a posterior plaster-of paris slab should be added to the collar and cuff sling

Immobilization should be continued for 3–4 weeks and then a sling applied with voluntary exercise to encourage motion in the joint

POSTERIOR DISLOCATION OF ELBOW WITH FRACTURE OF HEAD OF RADIUS

When this injury (Fig 213) occurs it is advisable to follow the general rule of first reducing the posterior dislocation and then treating the radial head fracture

Under regional or general anesthesia the dislocation should be gently reduced and check x ray films made to verify the reduction and determine the condition of the head of the radius The degree of disalignment and the character of the fracture will determine whether or not the radial head should be removed This problem is discussed on page 329 under Fracture of the Head of the Radius.

If the decision is made to excise the head of the radius this should be done either immediately or within a few days since



Fig 213 —Posterior dislocation of the elbow with fracture of the head of the radius

early removal has yielded better results than delayed or late removal

Following closed reduction of the fracture dislocation the after treatment is the same as in posterior dislocation of the elbow If the radial head is excised immediately after the reduction the after-treatment remains the same except that early voluntary rotation of the forearm is started the following day and is continued daily keeping within the limits of pain

POSTERIOR DISLOCATION OF ELBOW WITH FRACTURE OF EXTERNAL CONDYLE

Injury of this type is known to occur both in children and in adults but it is very rare When the forearm bones are displaced backward they may carry with them

a portion of the external humeral condyle This is usually caused by the head of the radius breaking off the under surface of the external condyle of the humerus as it dislocates backward instead of sliding under neath the condyle

Reduction of the dislocation is very likely to reduce the fracture also and for this reason the treatment is that used in posterior dislocation of the elbow with more rigid fixation and slightly longer immobili zation to allow the fracture to stabilize. displaced bone fragment is pressed back to the inner side of the joint from which it came and not allowed to get caught between the joint articulations To avoid this danger it is often helpful if the surgeon will knead and pull on the flexor forearm muscles with his fingers before the actual reduction is begun or while it is being car ried out. Should the detached epicondyle still remain in the joint after reduction (Fig 214 B) faradic stimulation of the flexor muscles can be tried since this treat ment is known to have been successful in extracting the bone fragment in such instances.

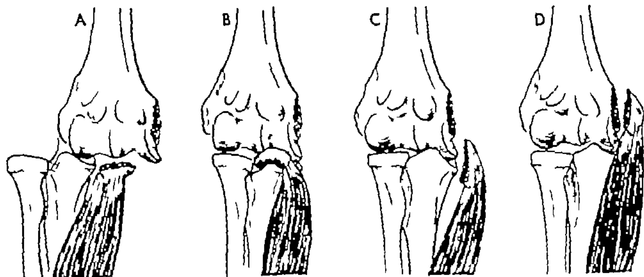


Fig 214 —Degrees of displacement of internal epicondyle A displacement of internal epi condyle following lateral dislocation of the elbow B incarceration of internal epicondyle in the joint after reduction of lateral dislocation of the elbow C fracture of internal epicondyle with wide separation of the fragment D fracture of internal epicondyle with minimal separation of the fragment

Lateral Dislocation of Elbow with Avulsion of Internal Epicondyle

This injury is usually the result of an outward dislocation of the elbow which pulls off the lateral ligaments and avulses the bony attachment of the flexor muscles of the forearm from the internal epicondyle of the humerus (Fig 214) Sometimes the detached piece of bone with its muscle and ligamentous attachment is drawn lateral ward along with the displaced forearm bones and it may lie beneath the articular surface of the humerus or even lateral to it (Fig. 214 *A*) *It is of the utmost* impor tance therefore when performing reduc tion of the dislocation to be sure that the

If the reduction of the dislocation is suc cessful by the closed method and the epi condyle is returned to its proper anatomical position with good approximation of the fractured surfaces (Fig 214 *D*) immobi lization should be employed with the elbow held in acute flexion by a collar and cuff sling plus a posterior plaster-of paris splint for 3 weeks.

If following closed reduction of the dislocation it is not possible to extract the displaced epicondyle from the joint or to obtain a satisfactory reduction of it (Fig.

214 C) then open reduction with operative replacement is indicated (Fig 215) At operation the displaced fragment is extracted from the joint and sutured or pinned back to its contiguous surface on the internal condyle

The results of both closed and open reduction are good

In this type of injury the ulnar nerve must be kept in mind because not infrequently the nerve is traumatized When nerve trauma occurs the resulting ulnar paralysis is fortunately only temporary and scarcely ever serious or permanent.

Lateral Dislocation of Elbow with Fracture of External Condyle

When the forearm bones are dislocated inward or medially at the elbow they may produce at the same time a fracture of the external condyle by tearing off a fragment of bone that forms the attachment of the extensor group of forearm muscles and the external lateral ligament Such an injury is the counterpart of an outward dislocation of the elbow with fracture of the internal epicondyle The broken condylar fragment may be drawn over to the opposite side of the joint with the forearm bones or be only slightly displaced depending on the severity of the injury If the fragment is detached and markedly displaced the same care must be taken to avoid its inclusion in the joint at the time of manipulation and reduction of the dislocation as was mentioned in the case of internal epicondyle displacements

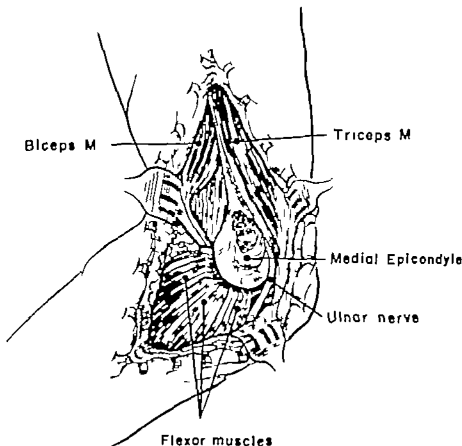


Fig 215 —Operative view of incarcerated internal epicondyle in elbow joint.

After the dislocation is reduced the elbow should be flexed and check x ray films made in order to determine the position of the fractured bone If the bone is found to be in satisfactory position the elbow flexion should be maintained for 3 weeks by means of a posterior plaster-of paris slab

and a collar and cuff sling then followed by an ordinary arm sling and voluntary *motion.*

If satisfactory reduction of the fracture cannot be obtained by the closed method of manipulation then *open reduction is* indicated with replacement and fixation of the fractured fragment in its normal anatomical position After-care consists of immobilization of the elbow in right angle flexion in a plaster casing for 3 weeks followed by the use of a sling and gradual use of the joint aided by voluntary exercises.

Anterior Dislocation of Elbow with Fracture of Olecranon

Anterior dislocations of the elbow *without* a fracture of the olecranon are extremely rare The injury results from a fall or a blow that strikes the back *of the upper forearm* causing a fracture of the ulna and forcing both forearm bones forward and upward in front of the lower *end of the* humerus Sometimes the ulnar nerve is stretched or injured and this possibility must be kept in *mind*

The treatment consists of reduction of the fracture-dislocation by the closed method which is usually not difficult to perform Traction is applied on the forearm *bones and* as the elbow is extended pressure is made backward on the front of the upper forearm.

If the reduction is satisfactory the elbow may be immobilized in extension with a plaster-of-paris slab Most surgeons prefer *however to perform an operative* reduction with internal fixation of the fractured olecranon which allows earlier function and a shorter convalescence Following operation the arm should be placed in a plaster-of paris casing with the elbow at right angle flexion for 6–8 weeks *In* such an injury excision of the proximal fragment of the ulna is contraindicated be*cause of the danger* of redislocation

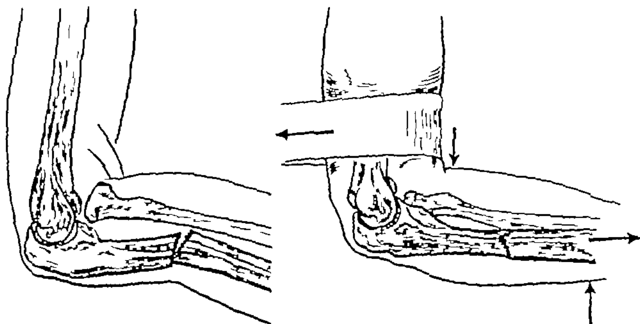


Fig 216 —Fracture of the shaft of the ulna with anterior dislocation of the head of the radius (anterior *Monteggia fracture*) *Left before* reduction *Right after reduction.*

Dislocation of Head of Radius with Fracture of Upper Third of Shaft of Ulna (Monteggia Fracture)

For a long time it was thought that this condition was the result of a direct force which struck the upper forearm from below causing a fracture of the ulna and driving the radial head upward out of *its articulation Such a fracture-dislocation*

was known as an *anterior* Monteggia frac ture (Fig. 216) in contrast to the type that resulted from a force striking the upper forearm in the opposite direction from above downward and causing fracture of the ulna and a posterior dislocation of the radial head This latter condition is commonly termed a *posterior* Monteggia fracture and is illustrated in Figure 217 were not caused by direct trauma While it is conceivable that direct trauma may produce a Monteggia fracture it seems that it rarely does so and is not the usual cause of the condition Forced pronation is a more logical and plausible explanation of the pathological process in this type of fracture Moreover Evans was able to reduce such fracture-dislocations by the

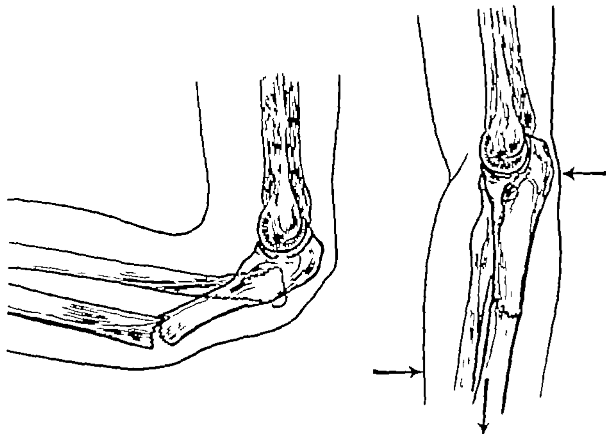


Fig 217 —Fracture of the shaft of the ulna with posterior dislocation of the head of the radius (posterior Monteggia fracture) **Left** before reduction. **Right** after reduction

Both types of Monteggia fracture used to be considered as requiring open operation the goal being to restore and maintain the full length of the ulna when the radial head would either automatically reduce itself or could easily be replaced and secured by suture of the orbicular ligament The best operation designed for this purpose is that of Boyd

It was not until 1949 that a new conception of the mechanism of Monteggia fractures was presented by Evans who demonstrated quite clearly that these fractures resulted from a "pronation injury" and closed method with very gratifying results His conclusions in the treatment of 11 Monteggia fractures by means of traction and supination as follows

1 In nine cases reduction of the radial head dislocation was achieved by closed methods and direct pressure on the radial head was required only twice When closed manipulation was successful full supination was usually necessary to reduce the dislocation but in one exceptional case reduction appeared to be more complete in mid-rotation and the limb was accordingly immobilized in this position

2 Two patients were submitted to operation In one case the fracture was two weeks

old and closed reduction failed in the other there was wide separation of the epiphysis of the radial head and operation was performed for its replacement. In both cases it was observed by direct vision that the superior radio-ulnar dislocation was reduced by full supination and recurred when the forearm was pronated.

3 At the end of treatment, radiographs in three rotational positions showed that in ten cases the superior radio-ulnar joint was stable

The patient was a boy aged ten years who caught the sleeve of his coat in the rollers of a machine His forearm was pronated with such force that he was picked up and whirled round twice before falling to the ground

It is of interest, in this regard, to note a quotation from Böhler s *Textbook on the Treatment of Fractures*

One of the errors in the treatment of frac

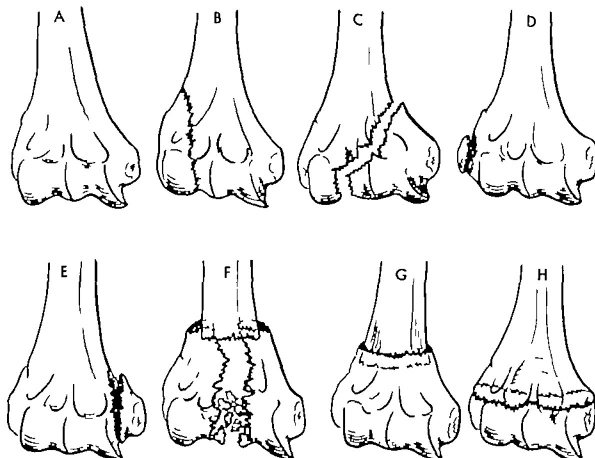


Fig 218 —Varieties of fractures at the lower end of the humerus A, normal bone B fracture of external condyle C fracture of internal condyle D fracture of external epicondyle. E fracture of internal epicondyle F T or Y intercondylar fracture G supracondylar fracture H intercondylar or dicondylar fracture.

and in perfect position In the one case in which late open reduction had been performed there was slight forward subluxation of the joint in all positions of rotation.

4 The fracture of the ulna united in all cases and the maximum period of immobilization in plaster was twelve weeks

5 In ten out of eleven patients the final range of elbow movement was approximately normal In the case in which the radial epiphysis was replaced at operation the final range of rotation was much restricted. *This case is* particularly interesting because of the history

ture-dislocations of the elbow is to operate on Monteggia fractures or on fractures of the ulna with dislocation of the head of the radius forward.

It is always possible to reduce the fracture-dislocation by sufficiently strong traction and side pressure

In view of past experience and recent studies on the treatment of this fracture it would seem that *Monteggia fractures* should not be allocated to the category of

operative fractures but that attempts should first be made to reduce them by the closed method of traction and supination

If closed reduction fails then open reduction should be performed through the operative approach of Boyd At operation the ulnar fragments should be reduced and secured by internal fixation then the radial head should be replaced and held by a suture of the torn annular ligament or a new ligament should be fashioned from fascia lata to prevent dislocation

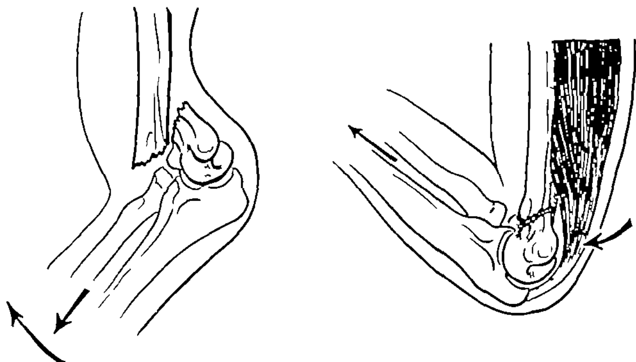


Fig 219 —The usual extension type of supracondylar fracture of the humerus **Left** before reduction **Right** after reduction

FRACTURES OF THE ELBOW

The fractures of the elbow may be classified as follows (1) fractures of the lower end of the humerus (Fig 218)—e g supracondylar fracture of the humerus (extension flexion and malunited types) transcondylar fractures of the humerus fractures of the capitellum (chip hemicapitellar and old ununited fractures and capitellar epiphysial separation) fractures of the external condyle of the humerus in adults and intercondylar T and Y fractures of the humerus (2) fractures of the upper ulna (fractures of the olecranon) and (3) fractures of the upper end of the radius (radial head fractures and separation of the upper radial epiphysis)

Supracondylar Fracture of Humerus

Probably the most common fracture of the elbow joint especially in children is the supracondylar fracture It is of two types depending on the position of the broken bone fragments If the distal fragment lies behind the lower end of the humeral shaft the fracture is termed the "extension" type of supracondylar fracture (Fig 219) whereas if it lies in front of the humerus it is known as the "flexion" type (see p 319 Fig 224) The extension type is the one most frequently seen and is also the most favorable from the point of view of treatment The flexion type is fortunately quite rare and much more difficult to treat

The deformity produced by these fractures is very similar to that of a posterior dislocation of the elbow and when marked swelling is present it may be very difficult

old and closed reduction failed in the other there was wide separation of the epiphysis of the radial head and operation was performed for its replacement In both cases it was observed by direct vision that the superior radio-ulnar dislocation was reduced by full supination and recurred when the forearm was pronated

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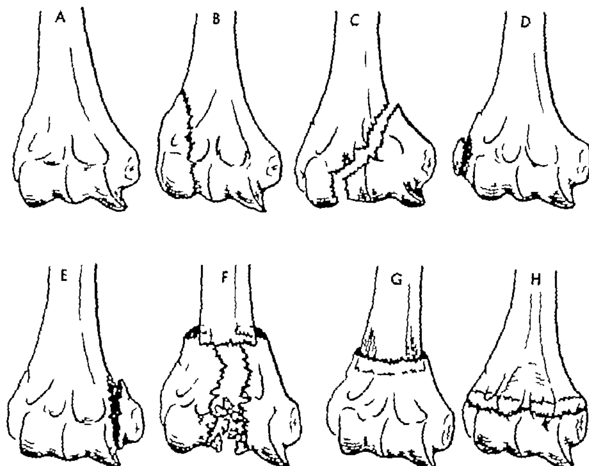


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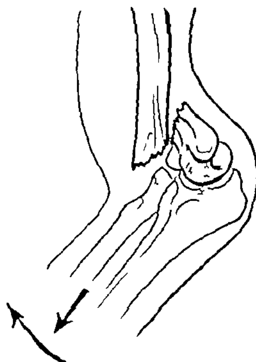
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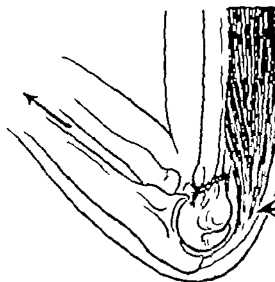


Fig 219 —The usual extension type of supracondylar fracture of the humerus Left reduction Right after reduction.

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or impossible to differentiate clinically between the two conditions In general it can be said that supracondylar fractures show a greater amount of mobility than posterior dislocations and that the anatomical relationship of the olecranon with the internal and external epicondyles is not disturbed in these fractures as it is in dislocations

As a general rule displacement of the distal fragment is corrected in the extension type by immobilizing the broken fragments with the elbow flexed while in the opposite type of fracture (flexion) the *distal fragment may have to be immobilized* with the elbow in partial or complete extension.

The Usual (Extension) Type of Supracondylar Fracture

TREATMENT —Under regional or general anesthesia the patient's upper arm is held by an assistant while the surgeon grasps the elbow with his left hand and the wrist with his right. The general alignment

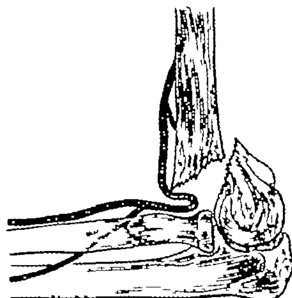


Fig 220 —Diagram illustrating the danger to blood vessels by flexing a supracondylar fracture before applying traction to it. Traction must always be applied first

of the arm is corrected by gentle pressure and manipulation with the surgeon's left hand then strong traction is applied as the arm is gradually completely extended. The manipulation plus traction should result in drawing the distal fragment down into proper relationship with the proximal fragment

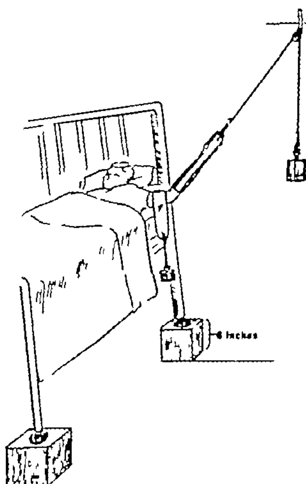


Fig 221 —Dunlop's traction (Tracing of a photograph)

and then—and not until then—the elbow should be flexed to maintain the reduction. In other words flexion of the elbow should never be attempted until manipulation and traction have first been performed because if done before it may produce extremely serious consequences by pinching and crushing the blood vessels and nerves in front of the joint between the sharp and ragged surfaces of the broken bone fragments (Fig 220)

It is well to remember that in supracondylar fractures of the elbow the movement of flexion does not *reduce* the fracture and may do irreparable damage It should be used only as a final maneuver to *maintain* the reduction.

As the surgeon flexes the elbow while maintaining traction he must be careful to avoid any rotatory displacement of the distal fragment. To prevent such displacement the arm should be held with the forearm in supination and with the anticubital space facing upward as the movement of flexion is carried out Once the desired degree of flexion is obtained the surgeon should immediately feel the patient s pulse to be sure that it is present and strong. The degree of elbow flexion for immobilization purposes is determined by the patient s pulse and should the position of acute flexion result in absence or weakening of the pulse the forearm should be lowered until the pulse beat is strong Sometimes the elbow is so swollen or the injury so severe that flexion cannot be obtained beyond a right angle without obliterating the pulse When such a situation arises it is well to employ another method of treatment such as Dunlop s traction (Fig 221) or overhead skeletal traction (Fig 222) Either of these methods will maintain traction on the arm keep the fracture reduced and at the same time aid the circulation by elevating the extremity thereby reducing the risk of Volkmann s contracture

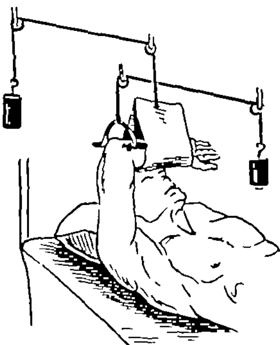


Fig 222.—Overhead skeletal traction.

It is a wise practice to use either Dunlop traction or overhead skeletal traction whenever there are any doubts regarding the circulation

In most instances the patient s arm can be safely flexed into a comfortable position that can be supported and maintained by a collar and cuff sling suspending the wrist from the neck. A strip or two of sheet wadding should be placed across the anticubital fold of the elbow as it is being flexed in order to avoid maceration of the skin In addition a plaster-of paris splint should be carefully molded to the posterior surface of the flexed arm from the posterior axilla to the metacarpophalangeal joints and secured by a lightly applied gauze bandage (Fig 223)

This posterior plaster-of paris slab should be applied immediately following the flexion of the elbow with the forearm supinated and the anticubital space facing upward and after a strong pulse beat is verified at the wrist The arm is held in this position until the plaster is well set *before* the arm is allowed to rotate against the



Fig 223 —Immobilization of supracondylar fracture by a plaster-of paris slab and a collar and cuff sling *following reduction*

or impossible to differentiate clinically between the two conditions In general it can be said that supracondylar fractures show a greater amount of mobility than posterior *dislocations and that the anatomical relationship* of the olecranon with the internal and external epicondyles is not disturbed in these fractures as it is in dislocations

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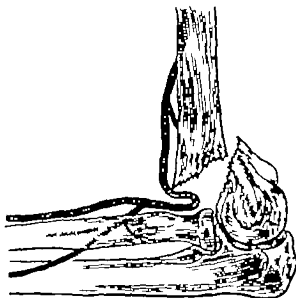


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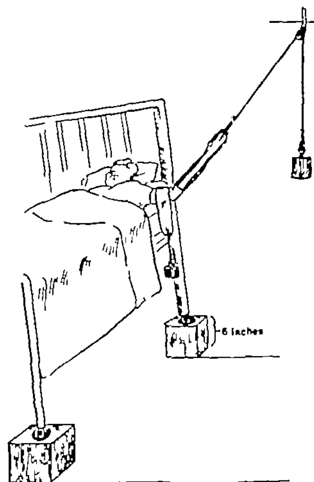


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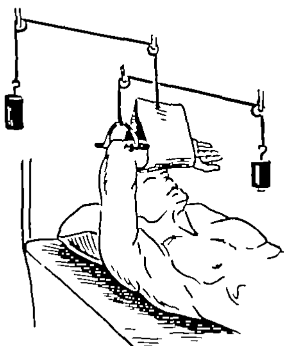


Fig 222.—Overhead skeletal traction.

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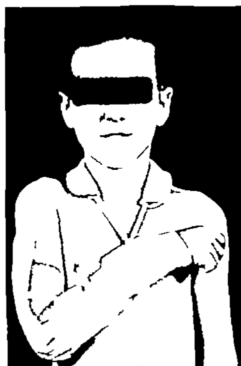


Fig 223 —Immobilization of supracondylar fracture by a plaster-of-paris slab and a collar and cuff sling following reduction

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Treatment —Under regional or general anesthesia, the patient s upper arm is held by an assistant while the surgeon grasps the elbow with his left hand and the wrist with his right. The general alignment

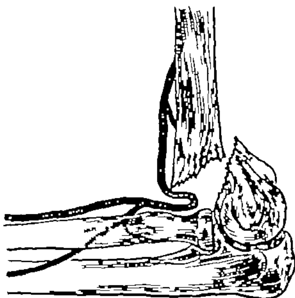


Fig 220 —Diagram illustrating the danger to blood vessels by flexing a supracondylar fracture before applying traction to it. Traction must always be applied first.

of the arm is corrected by gentle pressure and manipulation with the surgeon s left hand then strong traction is applied as the arm is gradually completely extended The manipulation plus traction should result in drawing the distal fragment down into proper relationship with the proximal fragment

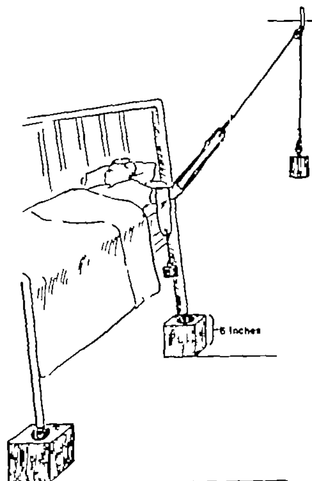


Fig 221 —Dunlop s traction (Tracing of a photograph)

and then—and not until then—the elbow should be flexed to maintain the reduction In other words flexion of the elbow should never be attempted until manipulation and traction have first been performed because if done before it may produce extremely serious consequences *by pinching and crushing the blood vessels* and nerves in front of the joint between the sharp and ragged surfaces of the broken *bone fragments* (Fig 220)

It is well to remember that in supracondylar fractures of the elbow the movement of flexion does not *reduce* the fracture and may do irreparable damage It should be used only as a final maneuver to *maintain* the reduction

tive acute flexion of the elbow if the fragments are stable in this position Watson Jones on the other hand believes that it is clearly wrong to treat this fracture in the flexed position and strongly advises complete extension He contends that traction followed by complete extension will reduce this type of fracture with no difficulty and that in the extended position it is easy to judge the carrying angle and apply any lateral pressure that may be necessary to correct any tilting of the lower fragment. Following reduction, a posterior plaster-of-paris slab is applied to the extended arm for 3 weeks after which if the reduction is perfect, full movements are easily recovered

It is apparent from the foregoing statements that there is a difference of opinion regarding the treatment of this rare fracture but it would seem that the position of complete extension offers the best chance of reduction and that if by chance it should fail then a reduction with x ray control will best determine what position is optimum for immobilization The after-treatment is essentially the same as that for other supracondylar fractures

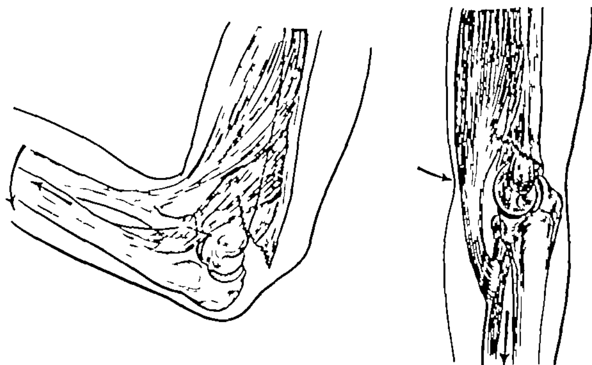


Fig 224 —The rare flexion type of supracondylar fracture **Left** before reduction **Right** after reduction.

Malunited Supracondylar Fracture

If the fracture is more than 3 weeks old and displaced there are two alternatives of treatment immediate operative reduction and delayed osteotomy

The deformities most likely to occur are a cubitus varus a cubitus valgus or a flexion block deformity The first two cubitus varus and cubitus valgus are the result of either incomplete reduction or epiphysial growth arrest and, when the deformity is marked, should be corrected by osteotomy It is well to defer the corrective osteotomy until normal motion has been regained in the joint and until full growth is attained unless the degree of deformity is extreme

When corrective osteotomy is to be performed it should be done with extreme care and precision In order to be sure of the desired result a paper tracing of the front x ray view of the deformed area should be

est wall and be suspended by the collar ıd cuff sling

If further fixation or reinforcement is sired an encircling wide strip of adhe- ˀe plaster or a figure-of-eight bandage can used to bridge the space between the iddle forearm and the middle upper arm

After Treatment —After the fracture s been reduced and the arm immobilized eck x ray films should be made in order determine if the reduction is satisfac ry If it is not a second attempt should made either immediately or after the elling has subsided depending on the gree of displacement and the severity of e injury It is sometimes necessary to ake several repeated attempts at reduc n before success is attained but as a le these fractures can nearly always be duced without resorting to skeletal trac m or operation.

When x ray examination shows the re ıction to be satisfactory the elbow joint ould be placed in the optimum position 45 degrees above the right angle if pos ɔle Frequently the amount of swelling at is present will not permit this degree of xion but as the swelling subsides flex n should be increased and new plaster ılints applied until the optimum position reached

Finger and shoulder exercises should be arted at once and after 3 weeks the collar ıd cuff sling with the plaster splint can discarded and only an ordinary arm ing retained for another week. The arm taken out of the sling at regular intervals r active exercises and mobilization but ıder no circumstances should passive ex cises massage or stretching be employed nce these measures may encourage the evelopment of myositis ossificans

The complications that are likely to oc ır in supracondylar fractures are Volk ann s contracture injury to nerves and ood vessels vascular obstruction from ght bandaging or splinting and myositis sificans These complications are so dan- rous and so tragic in their nature and ɔssibilities that every precaution should be taken to avoid them and for this reason it is advisable to have patients with supra condylar fractures hospitalized and kept under observation for at least 24 hours.

The prognosis of supracondylar frac tures in children is as a rule excellent. Careful and gentle manipulation plus trac tion is usually successful in obtaining a satisfactory reduction, and the position of acute elbow flexion maintains it. If be- cause of marked swelling or vascular dis- turbance the elbow cannot be safely flexed to above a right angle then Dunlop s trac tion or overhead skeletal traction should be employed to secure the reduction and reduce the swelling After 2 weeks the arm may safely be brought to the side and treated as an uncomplicated fracture As stated previously it is of the utmost impor tance in the after-care to avoid forcing the joint motion or using massage and passive stretching

In adults it should be mentioned the prognosis of supracondylar fractures is not so favorable as in children

The Flexion Type of Supra condylar Fracture

The flexion type of supracondylar frac ture (Fig 224) in which the distal frag ment is displaced upward and anterior to the lower end of the proximal fragment is fortunately quite rare It is also less likely to be complicated by blood vessel and nerve damage than is the extension type of fracture

Treatment —This fracture however is not nearly so easily and satisfactorily treated as is the usual extension type of supracondylar fracture reduction may be very difficult to accomplish and maintain. Because of this no one method of manipu- lation is considered ideal and several dif ferent procedures are suggested in the textbooks Key and Conwell for instance prefer the position of right angle flexion for immobilization after the fracture is re- duced by traction and manipulation al though they mention as a possible alterna

portion of the trochlea as well (Fig 226) As a rule they are much larger than they appear in the x ray film The fractured fragment is displaced directly upward on the lower end of the humerus hugging the shaft so that it may not be visible in the anteroposterior x ray view and may be overlooked The lateral view however reveals the displaced fragment clearly usually with its fractured base in apposition with the anterior cortex of the humerus and with its articular surface facing forward just as if the capitellum had been split in its sagittal plane and the anterior portion had slid upward out of its bed Sometimes not always possible to apply digital pressure at the desired point to effect reduction Following reduction the elbow should be held in acute flexion and this will usually be sufficient to maintain the reduction Immobilization should be continued for 4 weeks

Occasionally the fractured fragment may become slightly rotated and this makes closed reduction more difficult Nevertheless it should be attempted before resorting to open reduction

Should all the attempts of manipulation fail operative reduction is indicated An anterolateral approach should be used and



Fig. 226 —Typical hemicapitellar fracture before (left) and after (right) closed reduction.

the displaced fragment becomes rotated so that its articular surface faces the head of the humerus but this is not the usual finding

TREATMENT —The aim of treatment in hemicapitellar fractures is to slide the detached portion of the capitellum downward into the bed from which it arose and then hold it there by acute flexion of the elbow The forearm is extended and adducted at the elbow joint to widen the space from which the displaced fragment came Then while steady traction is being exerted on the extended arm local digital pressure is applied on the loose fragment pressing it downward into its proper anatomical position. Because of the marked swelling that may be present the reduction may require the aid of the fluoroscope otherwise it is when the joint has been opened the size and character of the broken fragment will determine whether it should be removed or replaced If the fragment is quite small or is comminuted and has no soft part attachments it should be removed If on the other hand, as is usually true it consists of one piece of bone that has been avulsed from its corresponding other half it should be carefully and accurately replaced and held in position by flexing the elbow Elbow flexion ordinarily supplies a stable reduction for this type of fracture and seldom is it necessary to employ any kind of internal fixation

It is only fair to state that some authorities look on this type of fracture in adults as an operative fracture and advocate the removal of the detached bone in all cases

made and cut to exact measurement so that the surgeon, noting the paper correction, will know the exact size of the wedge of bone that is to be removed from the humerus to produce a normal carrying angle Following removal of this wedge of bone the two bone fragments should be brought into apposition and held in their corrected alignment by some form of internal fixation preferably a small bone plate In this way the surgeon can be certain of the proper degree of correction, and motion of the elbow can be started at an earlier date

Should the deformity be one of flexion block, the treatment will depend largely on the age of the patient. In young children this deformity is usually outgrown and operative measures are unnecessary In adults however this is not the case and operative resection of the projecting mass of bone on the lower end of the humeral shaft is necessary to bring about improved motion

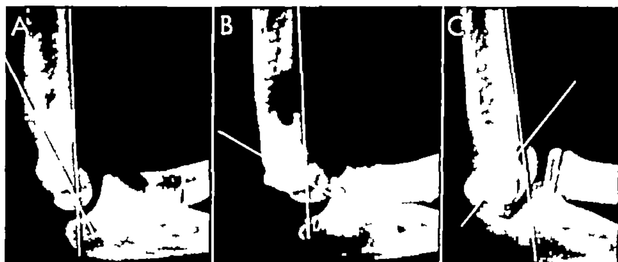


Fig 225 —Greenstick type of intercondylar fracture A, normal elbow B flexion type C extension type

Transcondylar and Diacondylar Fractures

These fractures occur at the level of the epicondyles and extend through the olecranon fossa. They can be of the greenstick type (Fig 225) or with separation, when the lower end of the humerus has the appearance of a fish tail They are intra articular fractures and therefore should be reduced as accurately as possible in order to avoid the danger of bone block. In other respects they are similar to supracondylar fractures and should be treated in the same way

Fractures of Capitellum

There are 3 usual types of capiteller fractures chip fractures hemicapitellar fractures and capitellar epiphysial separations with or without rotational displacement.

Chip Fractures

The chip fractures are frequently associated with fractures of the head of the radius and they are usually the result of the radial head striking the capitellum. They are characteristically moon shaped or elliptical and they generally lie detached as a loose fragment of bone Since they are detached from the capitellum and are deprived of blood supply they should be removed through a small incision over the outer side of the joint.

Hemicapitellar Fractures

These fractures comprise the anterior half of the capitellum and a considerable

by dislocation of the forearm bones on the lower end of the humerus Should this oc cur open reduction will probably be neces sary Reduction should include not only hairline replacement and internal fixation of the broken fragment but also a repair of the internal lateral ligament which is usu ally found to be severed If on the other hand the fracture line does not extend so far into the joint as to include the radial ridge of the trochlea (Fig 231 B) the broken fragment may be treated by either closed or open reduction without any fear of dislocation.

Following either closed or open reduc tion of this fracture the elbow should be immobilized in flexion in a posterior plaster of paris molded splint for 2–3 weeks The splint should then be retained for night use but during the day a sling is sufficient and active exercises should be begun keep ing within the limits of pain

Intercondylar T and Y Fractures of Humerus

These fractures occur most frequently in adults and are caused by a blow or force striking the under surface of the upper ulna driving the wedge-shaped olecranon upward between the humeral condyles and separating them There may also be a trans verse fracture of the lower humeral shaft as well as various degrees of comminution of the bone fragments and damage to the articular surfaces of the joint.

Treatment —Treatment will depend on the character and severity of the fracture If separation of the broken fragments is only slight and satisfactory alignment is present a closed reduction with plaster-of paris fixation is all that is necessary the elbow being held in position of right angle flexion

If however there is wide separation of the fragments with over riding or disalign ment of the humerus and marked commi nution, then overhead skeletal traction with a Kirschner wire in the upper end of the ulna is indicated This method of treatment will restore the proper length of the hu merus correct any disalignment and allow further manipulation of the comminuted bone fragments (if thought necessary) while traction is being continued Also it will permit a certain degree of early active motion

If however the fracture consists of two three or four separate large discrete frag ments which are separated by soft parts or which resist an attempt at closed reduction or which are so displaced as to disrupt the articular surface of the humerus the treat ment recommended is open reduction

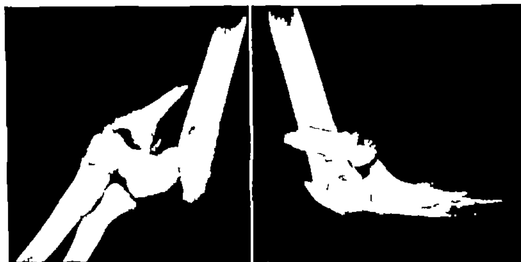


Fig 232.—Anteroposterior and lateral views of a T or Y fracture of the humerus Attempt at closed reduction was unsuccessful.

If open reduction is performed it should be done with a minimum amount of dissection in order to preserve the blood supply of the detached fragment The fragment with its muscle attachment should be replaced accurately and fixed in its anatomical position with either a suture or a fine steel pin or screw care being taken to avoid damage to the epiphysis After-care is the same as with closed reduction.

OLD UNUNITED FRACTURE OF CAPITELLUM —Not infrequently owing to failure of accurate reduction of a capitellar epiphysial fracture nonunion results and with the course of time more displacement takes place causing a growth arrest with cubitus valgus deformity (Fig 229) Sometimes the deformity becomes so extreme as to produce an ulnar nerve palsy necessitating an anterior transplantation of the nerve

If seen in a young person within a year or two after injury this condition should be corrected by an open reduction with repair of the nonunion if at all possible rather than by excision of the ununited bone fragment (Fig 230)

If the condition has been present for several years and if elbow motions are unrestricted and painless the deformity of the carrying angle should be corrected by osteotomy

FRACTURE OF EXTERNAL CONDYLE OF HUMERUS IN ADULTS

This fracture (Fig. 231) is sometimes associated with a fracture of the capitellum and is of unusual importance because of its possible effect in producing a lateral dislocation of the radius and ulna which may not be recognized If the fracture is complete and includes the radial ridge of the trochlea then a reduction may be impossible to maintain by any closed method because of lack of articular support for the ulna, which depends on this ridge for its stability (Fig 231 C) Without this support the ulna slips laterally and it is likely to remain in this dislocated position along with the radius unless it is replaced accurately and securely by open operation

The importance of this fracture depends on its location with reference to the trochlea If the fracture line extends into the midportion of the joint and is mesial to the radial ridge of the trochlea the situation is serious and likely to be complicated

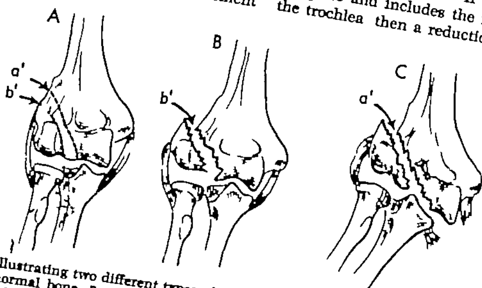


Fig. 231 —Illustrating two different types of fracture of the external condyle of the humerus in adults **A**, normal bone **B** stable type of fracture (represented by *b'*) which does not include the lateral lip of the trochlea and can be safely treated by closed reduction **C**, unstable type of fracture (shown by *a'*) which includes one half of the trochlea and offers no possible fixed support for the ulna or radius This type of fracture usually requires open reduction with internal fixation and possible repair of the ruptured internal lateral ligament

by dislocation of the forearm bones on the lower end of the humerus Should this occur open reduction will probably be necessary Reduction should include not only hairline replacement and internal fixation of the broken fragment but also a repair of the internal lateral ligament which is usually found to be severed If on the other hand the fracture line does not extend so far into the joint as to include the radial ridge of the trochlea (Fig 231 *B*) the broken fragment may be treated by either closed or open reduction without any fear of dislocation

Following either closed or open reduction of this fracture the elbow should be immobilized in flexion in a posterior plaster of paris molded splint for 2–3 weeks The splint should then be retained for night use but during the day a sling is sufficient and active exercises should be begun keeping within the limits of pain

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If however there is wide separation of the fragments with over riding or disalignment of the humerus and marked comminution then overhead skeletal traction with a Kirschner wire in the upper end of the ulna is indicated. This method of treatment will restore the proper length of the humerus correct any disalignment and allow further manipulation of the comminuted bone fragments (if thought necessary) while traction is being continued Also it will permit a certain degree of early active motion.

If however the fracture consists of two three or four separate large discrete fragments which are separated by soft parts or which resist an attempt at closed reduction or which are so displaced as to disrupt the articular surface of the humerus the treatment recommended is open reduction

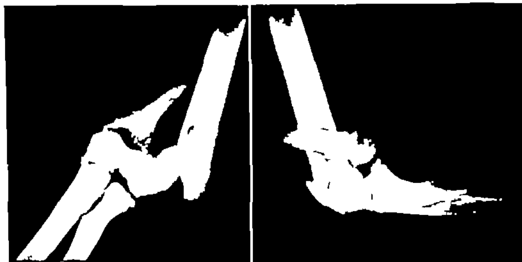


Fig 232.—Anteroposterior and lateral views of a T or Y fracture of the humerus Attempt at closed reduction was unsuccessful.

(Figs 232 and 233) In making this last recommendation it is assumed that the surgeon has had a large and adequate experience in fracture surgery and that the necessary specialized armamentarium for internal fixation is at hand also that the operation has been planned and studied before it is undertaken Such requirements are absolutely essential for the success of the operative treatment of these fractures

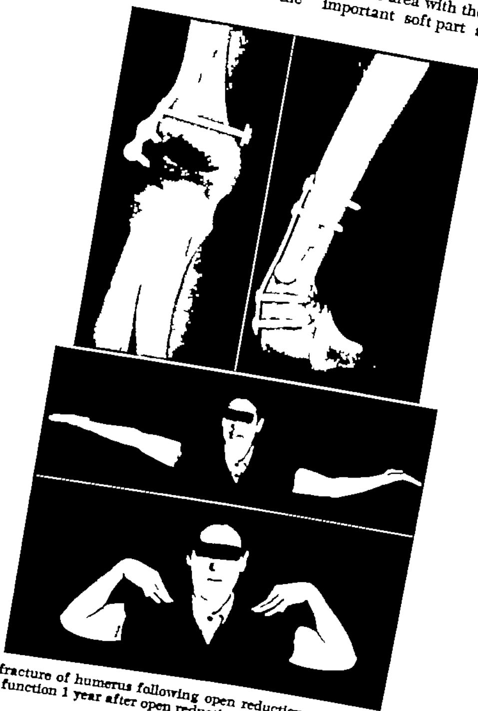


Fig 233 —*Top* fracture of humerus following open reduction and internal fixation *Bottom,* two views showing function 1 year after open reduction of intercondylar T fracture of humerus.

The best operative procedure is that which affords the widest exposure of the fracture area with the least involvement of the important soft part structures These requirements are most easily and satisfactorily met by a posterior surgical approach to the elbow joint (Fig 234)

If at the time of operation the broken fragments are accurately reduced and firmly fixed by plates screws bolts or

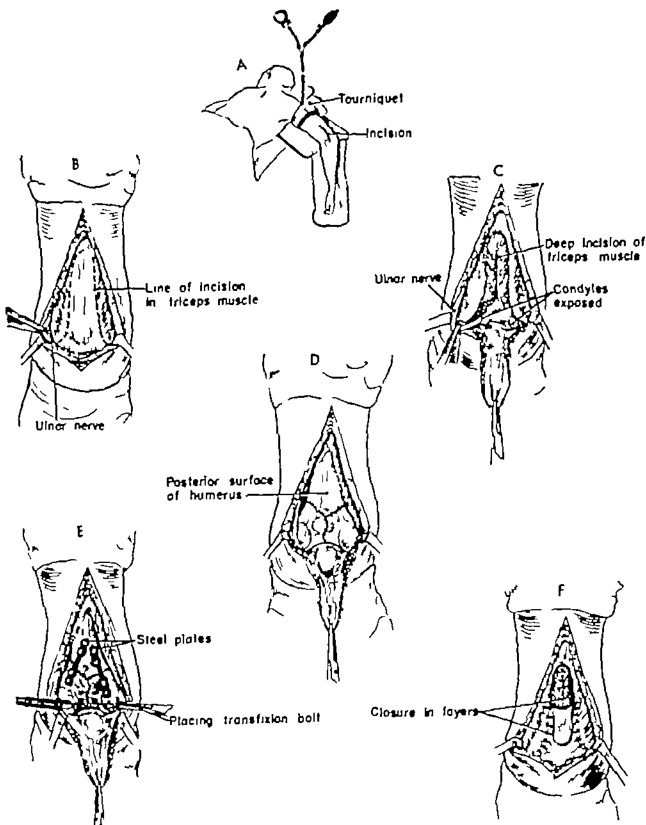


Fig. 234.—Operative technique for surgical approach in supracondylar T and Y fractures of the humerus requiring open reduction. A, proper position of the patient (face down) on the operating table for posterior exposure of the elbow joint. B, exposure of the triceps fascia and isolation of the ulnar nerve. C, dissection of fascial tongue and further exposure of the ulnar nerve. D, retraction of all soft parts and exposure of fracture area. E, internal fixation of the fracture with stainless-steel plates and transfixion bolt. F, closure of fascial tongue before subcutaneous tissues are approximated.

whatever kind of internal fixation is required the elbow can be mobilized almost at once and convalescence will be greatly shortened.

A posterior plaster-of paris splint or bivalved plaster casing should be used for immobilization immediately after operation and retained for a few days to a week after which it should be removed during the day to allow active motions of the joint and be reapplied for night protection for a period of 3 weeks From then on a sling may be continued if necessary being removed for active exercises and finally discarded after 4–5 weeks

There is no question but that intercondylar T and Y fractures of the humerus are usually very serious injuries and extremely difficult to treat requiring the very best of surgical judgment and skill

Fracture of Olecranon

Fractures of the olecranon occur much more frequently in adults than in children and are more serious and extensive in the older age group In children there is much less likelihood of displacement and comminution and therefore less necessity for radical measures of treatment. In fact the great majority of olecranon fractures in children are linear or greenstick in type and can be successfully treated by either a sling or immobilization in a plaster-of paris casing with the elbow held at right angle flexion for a week or two or if necessary in complete extension depending on the character and severity of the fracture

In adults the situation is entirely different When there is any separation of the bone fragments or when the fracture is

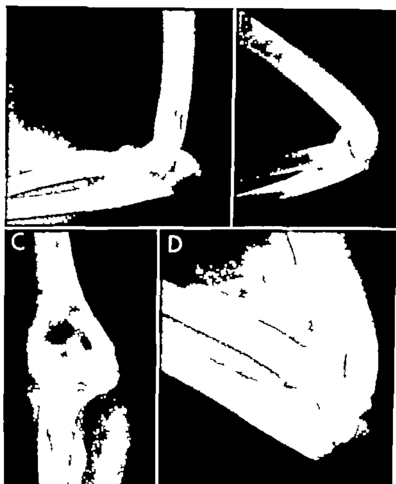


Fig. 235 —Fracture of the olecranon A before operation B after excision of proximal fragment C extension D flexion 1 year after excision of proximal fragment excellent function.

compounded excision of the proximal fragment or open reduction with internal fixation of the fragments is definitely indicated In other words this fracture in adults should be considered an operative fracture unless the local skin condition or senility contraindicates this treatment

Many materials have been used for internal fixation of these fractures but the materials preferred in the Fracture Clinic at Massachusetts General Hospital are stainless-steel wire short Rush nails long stainless-steel wood screws and fascia lata

The last mentioned material (fascia lata) is mainly employed in the repair of the triceps tendon in those cases where the proximal fragment is excised because of extensive comminution making it unsatisfactory for articulation with the humerus

The operation of excision of the proximal portion of the fractured olecranon as recommended by Watson-Jones and by Mc Keever and Buck is looked on with great favor at Massachusetts General Hospital, especially for older persons since it eliminates the long period of bone healing and offers an excellent end result (Fig 235) It probably will be used with greater frequency as time goes on. The requisites for excision are (*1*) an intact coronoid process and (2) an elbow that is stable at the time of exposure without repair of the olecranon.

Rombold s method of fascial repair (Fig 236) which has not been used at Massachusetts General Hospital undoubtedly would be useful in certain instances where the proximal fragment is too long to excise and is so comminuted that it will not provide any adequate fixation for either a nail screw or wire

Fracture of Head of Radius

Fractures of the head of the radius in adults are quite common and are a much more serious injury than they appear to be. Disability is often prolonged and some limitation of motion in extension or in rotation is a common permanent finding The injury usually results from a fall on the outstretched hand which forces the radial head against the capitellum and produces one of three types of fracture (1) the fissure fracture with little or no displacement (2) the marginal fracture with expulsion of a sector of the radial head and (3) comminuted fractures of the radial head

Fissure Fracture

Although this type of fracture often appears insignificant by x ray examination it may become very painful and disabling shortly after injury, owing to bleeding into the joint Bleeding should be anticipated and recognized when local swelling, pain and increasing limitation of motion appear and immediate aspiration should be performed under local anesthesia. Following evacuation of the hemarthrosis which usually gives immediate relief of pain, the arm should be immobilized [illegible] molded plaster-of paris [illegible] and cuff sling, with the elb[illegible] flexion. This splint should be [illegible] a day or two principally [illegible] then discarded and only the [illegible] While the arm is in a sling [illegible] moved several times a day [illegible] exercises in flexion, extens[illegible] tion care being taken to [illegible] limits of pain No passive [illegible] massage should ever be [illegible] swelling recedes the sen[illegible] pears and motion steadily [illegible] ever it may take several [illegible] recovery and frequently [illegible] tained because of failure [illegible] plete extension.

Marginal Fra[illegible]

This type of radial hea[illegible] as a triangular segment [illegible] tion of the bone which [illegible] separated from the ma[illegible] separated it usually is [illegible] what tilted and widen[illegible] with rotation or it [illegible] the articular surface [illegible]

If the fragment [illegible]

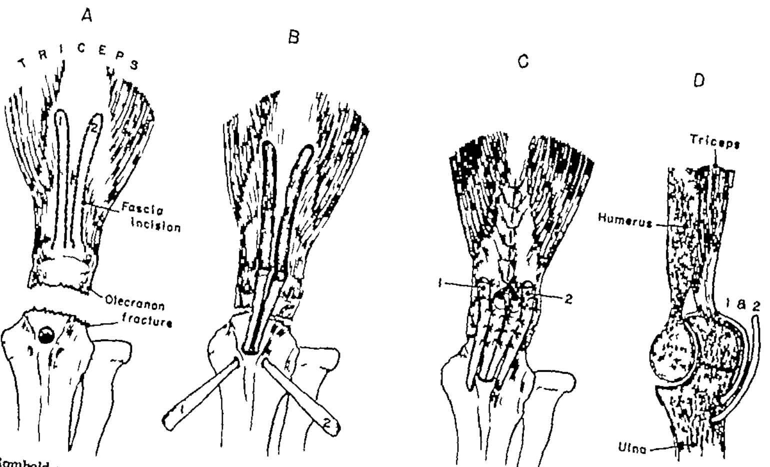


Fig. 236.—Rombold's method of fascial repair for fracture of the olecranon. A, lines of incision in the triceps fascia to obtain two fascial strips (*1* and *2*) which are left attached at their distal ends. B, the passing of fascial strips *1* and *2* through drillholes in the ulna for purposes of reduction and fixation. C, fascial strips *1* and *2* drawn taut to approximate the broken bone fragments and reinforce the fracture area. D, lateral view of the placement of the fascial strips *1* and *2*.

pressed but is in good alignment the same treatment should be carried out as is used for fissure fractures If on the other hand there is distortion of the articular surface of the radius owing to tilting and widen ing or if the fractured fragment is com pletely separated from the main bone then total excision of the head of the radius is indicated and should be done as soon as possible

At operation it is a great temptation to remove only the displaced sector since it nearly always arises from the outer side of the radial head the portion which does not articulate with the ulna Experience has shown, however that the results of local excision are not so certain of success from the point of view of function as is total excision of the head.

Comminuted Fracture

Comminuted fractures in adults if treated conservatively result in marked restriction of motion and disability and therefore they should be operated on at once with total excision of the head of the radius (Fig 237) The sooner the opera tion is performed, the better preferably it should be done within 24 hours Also at the time of operation great care should be taken not only to excise the head cleanly but to remove all of the tiny bone particles that may be present in the exposed area To accomplish this suction and irrigation of the wound using ample saline solution should be standard procedure in this opera tion With careful removal of all of the bone particles from the wound there will be less likelihood of the development of myositis ossificans which must be avoided if possible



Fig 237 —Comminuted fracture of the head of the radius before (*left*) and *after* (*right*) excision Perfect function 1 year later

After-Care

The after-care of cases of excision of the head of the radius consists of support of the arm at right angle flexion in a sling and early active exercises starting a day or two after operation The range of motion is in creased as rapidly as the elbow joint will allow within the limits of pain No passive or forceful movements should ever be per mitted nor should massage or manual manipulations be employed

Separation of Upper Radial Epiphysis

Fractures of the upper end of the radius in children either are of the greenstick type

involving the neck, a type easily reduced or they involve the epiphysis which suffers displacement rather than fracture When the displacement is partial, the epiphysis resembles a drum major s hat, cocked over on one side of the proximal end of the radial shaft (Fig 238) but when the displacement is complete the epiphysis appears as a smooth round disk, one surface of which is articular cartilage and the other raw cancellous bone (Fig. 239) Being an



Fig 238 —Slipped upper radial epiphysis with usual characteristic deformity

epiphysis preservation is of the utmost importance for growth purposes and, therefore every effort should be made to replace the fragment with accurate reduction Sometimes when the displacement is slight accurate replacement can be accomplished by closed reduction under anesthesia, the forearm being gently rotated while thumb pressure is exerted over the anterior and lateral aspect of the distorted radial head.

Should the attempt at closed reduction fail, however which often happens or should the displacement be marked or complete immediate operative replacement is demanded. Fortunately the replaced epiphysis usually remains reduced and no internal fixation is required. It is advisable at the time of operation, to test the stability of reduction with the elbow in various degrees of flexion and rotation and select that position for immobilization which offers the greatest security Immobilization in a plaster-of paris casing should be continued for 3 weeks followed by the use of a sling and active exercises within the limits of pain. No massage or passive stretching or manipulation should be permitted at any time

As a rule the results of separated upper radial epiphyses are good if the injury is treated as outlined above

The conclusions from the treatment of a series of 15 cases of slipped upper radial epiphyses at the Massachusetts General Hospital are as follows

1 Open reduction of separated upper radial epiphyses may result in either (*a*) complete fusion of the epiphysis (*b*) partial fusion of the epiphysis (c) nonunion of the epiphysis or (*d*) continued growth of the epiphysis

2 Where the epiphyses fused completely (7 cases) the normal carrying angle of the *elbow definitely increased into a valgus deformity* during the remaining period of growth where the epiphyses *partly* fused (2 cases) the carrying angle also increased but to a lesser degree In one case of non union of the epiphysis the carrying angle after a period of 3 years was 15 degrees greater than in the opposite arm In the cases where the epiphysial lines remained open (15 cases) the carrying angle remained normal as time went on

3 No single case in this series had a perfect end-result. Whereas disability was usually very slight and only 1 patient gave a complaint of pain, careful examination revealed some resulting abnormality or limitation of joint motion

4 The most frequent limitation of joint motion was pronation, which although

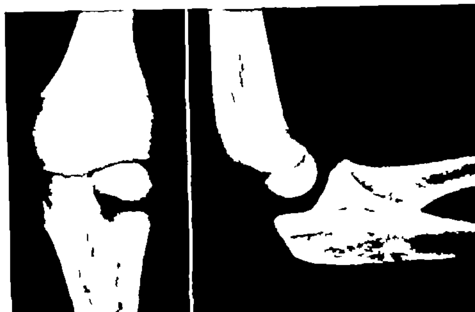


Fig 239 —Anteroposterior and lateral views of a case of slipped upper radial epiphysis with wide separation (disk type)

slight occurred in 80 per cent of the pa tients

5 From the point of view of function the end results in cases treated by open re placement of the upper radial epiphysis were on the whole very satisfactory

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Fractures of the Forearm

ANATOMY

IN FRACTURES of the radius and ulna the preservation of forearm rotation requires exactness in treatment Both bones are curved in two planes In the position of full supination the radius has a faint lateral bow the ulna has a slight medial bow and both are somewhat concave volarward (Figs 240 and 241) When the posterior bow of the radius or of both bones is increased supination is limited by impingement of the radius against the ulna When an anterior bow of the radius or of both bones exists pronation is restricted.

Except for the pronator quadratus muscle which causes appositional deformity (Fig 242) all the forearm muscles pull in a direction which produces shortening or bowing of the radius and ulna. Rotational deformity of the radius alone may exist in fractures of the radius above the level of the insertion of the *pronator radii teres the* supinator muscles will tend to pull the proximal fragment into supination while the pronator muscles will pull the distal fragment into pronation (Fig 243) a counter rotatory effect somewhat suppressed by the interosseous membrane and by the extended insertion of the supinator muscle

Malrotation alone cannot exist in a curved bone In the common fresh forearm fractures with disruption of bone at a single site or in a limited area, but without distortion of the natural curving contours of the fragments reduction of the fractures to normal linear alignment and normal bow will achieve proper rotatory alignment. But with loss of normal shaft curves in com*minuted fractures or in old malunited or* callus-surrounded ununited fractures special care must be taken to insure that a normal rotatory relationship of the proximal to the distal radius is achieved Evans has described a special method of radiological examination which is a valuable aid in establishing this relationship

The interosseous membrane (Fig 240) which joins the distal three fourths of the radius to the distal two thirds of the ulna can become tightened by scarring around the fractures in these areas and when infection or poor reduction has delayed healing of forearm fractures such scarring will restrict the recovery of rotation even though a late open operation may achieve union in excellent position.

Within the wrist joint the strong triangular ligament (Fig 240) extending from the ulnar side of the radius to the ulnar styloid is often torn in injuries that break and deform one forearm bone but leave the other intact. Scarring around the ligament within the joint and instability at the distal radio-

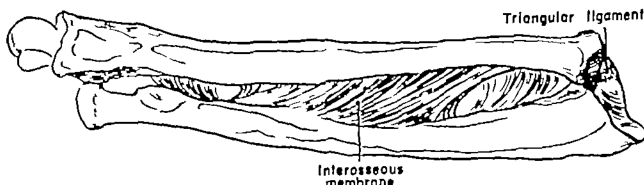


Fig 240 —Interosseous membrane and triangular ligament. Fractures through the area where the interosseous membrane fibers are denso are more likely to result in limitation of rotation than are fractures toward the extremities of the shafts





Fig 241 —Curves of the radius While the ulna is considerably curved in its proximal half in the distal portion the bone is broad and the medullary canal is large The radius in contrast is curved slightly in both planes and except in the distal third the medullary canal is narrow Much of the breadth of the midportion of the radius consists of the interosseous crest—a thin wedge of dense cortical bone

ulnar joint are causes of wrist pain after forearm fractures

INCIDENCE: AGE AND SEX DISTRIBUTION

Fractures of forearm bones have comprised about 5 per cent of all the fractures treated at the Massachusetts General Hospital Of these only 15 per cent occurred in adults with more fractures in men than in women. In children the fractures were divided equally between the sexes

MECHANISM OF INJURY

Most forearm fractures result from falls on an outstretched arm When direct blows break forearm bones the fracture often is comminuted.

X RAY EXAMINATION

Proper x ray examination of a fractured forearm requires anteroposterior and lateral views including the elbow and the wrist. Oblique views are often helpful and views of the opposite forearm are valuable

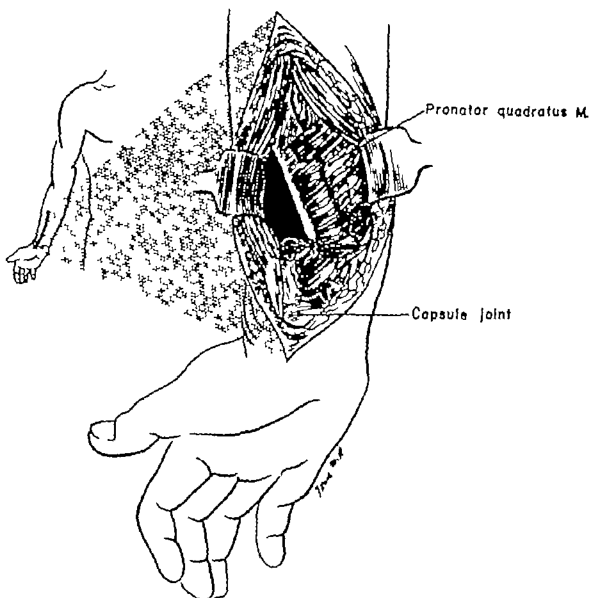


Fig. 242.—The pronator quadratus muscle pulling in a direction transverse to the shafts of the bones apposes the radius and the ulna in fractures of the distal forearm The fibers of this muscle are often interposed between bone fragments interfering with reduction.

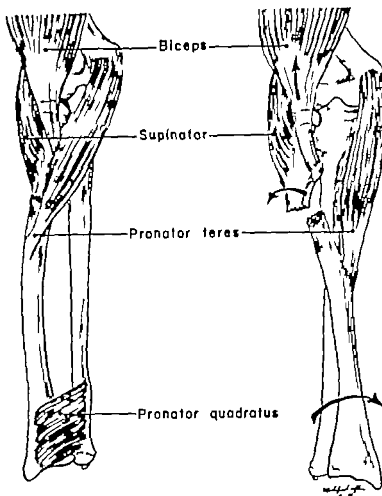


Fig 243 —Rotatory pull of forearm muscles In a fracture of the radius above the insertion of the pronator teres and below the insertion of the supinator (left) rotation deformity occurs as a consequence of biceps and supinator pull on the proximal fragment, and pronator teres and pronator quadratus unopposed pull on the distal fragment (right)

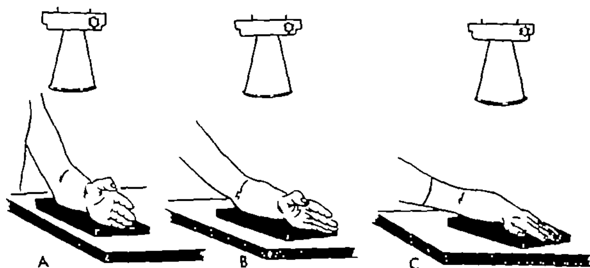


Fig 244 —Positioning of forearm for lateral (A) oblique (B) and anteroposterior (C) projections during radiography The forearm maintains a constant relation with the arm and is not rotated during changes of position.

Fig. 245 —"Bucket traction" This arrangement applies the traction of a bucket, weighted with water to the forearm during reduction of radial and ulnar fractures A piece of basswood spreading the strap from which the bucket hangs allows application of above-elbow splints without disturbing the position of the forearm

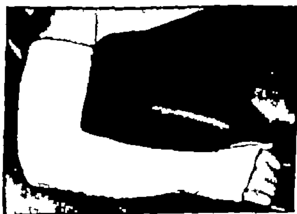


Fig 246 —A proper cast for immobilizing forearm bones The plaster casing follows the natural contours of the forearm and extends from the metacarpal necks to the axilla

at times particularly in children Films taken before and after rotation of the fore arm on the elbow through a 90-degree arc will allow picturing two projections of the radius but will yield duplicates of a single view of the ulna Such an examination is not adequate a true 90-degree change of position of the whole upper extremity is necessary (Fig 244)

TREATMENT

ANESTHESIA

The complete muscle relaxation that is necessary for manipulation and reduction of most forearm fractures requires either general anesthesia or brachial plexus block

CLOSED REDUCTION BY MANIPULATION

In nearly all closed forearm fractures an attempt should be made to achieve reduc tion by traction and manipulation.

Manipulation is best done after sustained traction against countertraction applied above the flexed elbow has been achieved This can be obtained by the pull of assist ants or by the use of a simple apparatus like that illustrated by Figure 245 which is set up as follows The hand is suspended by the three middle fingers from a stand such as that used for intravenous therapy and counter traction is applied by hanging a weight from a broad band across the arm above the flexed elbow A water bucket filled to provide the desired weight is a readily available traction device and the stand can be adjusted to a height to provide the desired 90-degree elbow flexion Ordi narily a traction force of 10 pounds exerted for 10 minutes fatigues muscles sufficiently to allow relaxation Manipulation is done at the fracture site by the surgeon s fingers After traction has been applied angulating or increasing the deformity of the fracture may serve to allow reduction of one bone which may then be used as a fulcrum for the reduction of the other Interposition of muscle between the bone ends is a common cause of prevention of reduction

The thick hard and relatively brittle cortex of the radial and ulnar shafts allows easy breaking-off of irregularities of frac ture surfaces during manipulation making fractures of these bones generally less stable than those of other long bones Posi tion is lost easily In more than half of all forearm fractures after what initially ap- peared to be stable reduction some degree of redeformity occurred at various times after reduction even as late as the fourth week

After reduction is confirmed by portable x ray films the arm is held by plaster ex tending from the necks of the metacarpal bones to the axilla The plaster may be ap- plied in the form of a molded circular cas ing Plaster slabs or splints are satisfactory fixation when applied carefully to fit the arm (Fig 246) Very thick slabs will not mold closely to the arm and if heavy splints are required they should be applied in layers each molded carefully as it is applied The plaster should hold the elbow at 90 degrees flexion and the forearm in the position in which the fragments are most stable When rotation is lost after fracture ordinarily it is supination which is most severely affected and therefore the posi tions of midrotation or of supination are preferable

Maintenance of the reduction requires adjustment of the plaster casing as swell ing subsides and muscles atrophy snug ging of splints by rewrapping bandages and guttering both sides of solid casts or chang ing them will accomplish this Frequent x ray examination is important and if po- sition is lost remanipulation is required if there was reasonable stability of reduction at the time of first manipulation. If reduc tion cannot be maintained open fixation is done

In adults reduction is acceptable only if there is no over riding and if the natural contour of the bones is restored Moderate displacement of one fragment upon the other in the lateral or anteroposterior planes will not jeopardize functional recovery Angulation of more than a few degrees may be expected to increase in the early post



Fig 247 —A, the original fracture B loss of position 4 days after reduction Remanipulation *did not achieve stable reduction C, open reduction with fixation of both bones by tibial graft* and four screws D 1 year after open reduction Function is normal.



Fig 248 —Unusual improvement of ulnar contour after union in poor position. A, the original reduction. B 10 weeks after reduction C 5 months after fracture With fracture of both bones at one level there was no damage to the distal radioulnar joint or the triangular disk and the patient did not have pain. He used the arm vigorously and had full return of function

reduction period when it affects the upper and middle thirds of the bones and such angulation will interfere with rotation (Fig 247) In the distal third of the bones a slightly bowed position may remain stable (Fig. 248)

Immobilization must be maintained until union is firm by x ray demonstration The average period required for this in adults when reduction is good is about 10 weeks but may be considerably longer

Reduction by Open Operation

The decision to openly reduce fractures should in most cases be made only after closed reduction has failed Occasionally in adults oblique fractures of both bones in which failure of closed treatment might be predicted need not be manipulated and the surgeon may be justified in proceeding immediately to open operation. Knight and Purvis found that the functional results after open fixation with grafting of forearm fractures in adults were satisfactory in 60 per cent of cases while only 29 per cent of cases treated by closed reduction were functionally satisfactory Although more than half of all forearm fractures in adults may have to be openly fixed in order to achieve satisfactory functional results there remains a large number of cases which can be treated perfectly well by manipulative reduction, and these patients should not be subjected to the risks of operation unnecessarily

If open fixation is done late it is more difficult and the functional results are poorer than is true in cases operated upon within a few days after injury In operating on fractured forearms which have been unreduced for even a period as brief as 10 days the surgeon comes to appreciate by the difficulty often encountered in reapposing the bone ends the rapidity with which muscles shorten and scarring of the inter osseous membrane occurs Except in unusual instances of vascular or nerve injury however operation on closed forearm fractures is not critically urgent and delay is justified in order to insure that the skill and equipment necessary for proper operation are available

Operative Technique.—Exposure of the entire radius or any portion of it can be gained through the incision described by Henry The ulna is nearly subcutaneous throughout its length and is approached

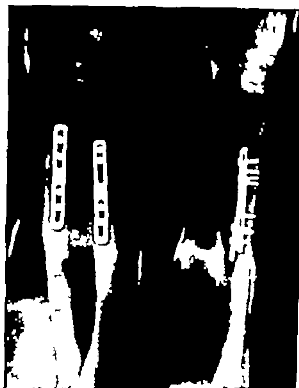


Fig 249 —Eggers plates with 4 screws used with bone-bank grafts at open reduction 10 days after fracture (Closed reduction could not be achieved because of muscle interposition.) The plates were applied on the flat surfaces of the radius and ulna and they fixed the bones securely enough so that, despite the development of sepsis in the ulnar wound position was not lost and union occurred At 1 year function was normal.

directly When both the radius and ulna are to be operated on, a separate exposure of each bone must be made

In adults firm internal fixation of the fracture is necessary *This can be accomplished* by the use of a bone graft fixed by 4 screws (Fig. 247 C) by a plate and screws (Fig 249) or in some fractures by an intramedullary nail (Fig. 250) *In an* oblique fracture *only rarely will screws* alone provide adequate fixation *The occur* rence of nonunion after fixation by plates

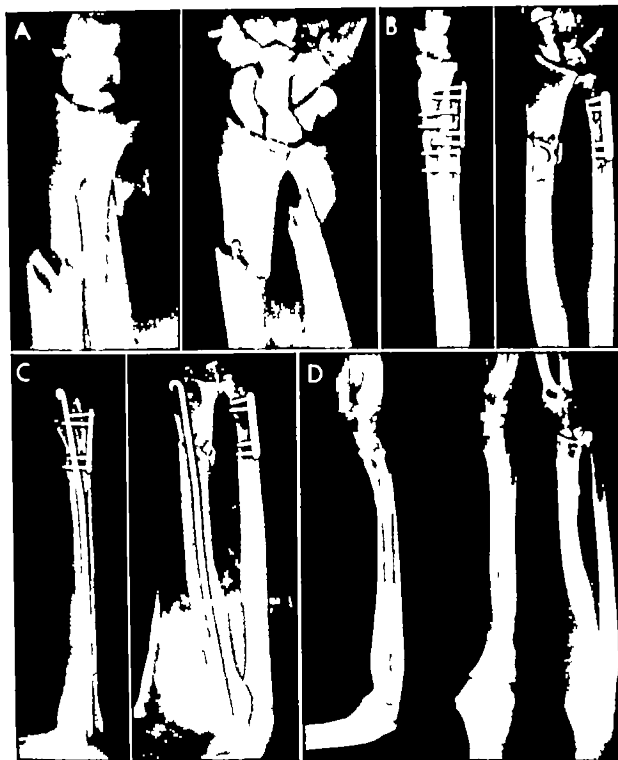


Fig 250 —Use of Rush nail to stabilize distal radial fracture A, the original fracture a con sequence of a wringer injury B closed reduction not achieved because of interposition and pull of the pronator quadratus muscle Open reduction and fixation of the radius by a flat iliac graft and 4 screws, and of the ulna by a plate and screws were done Comminution of the ulnar cor tex of the radius made this fracture an unstable one the strength of the flat iliac graft was in adequate and the graft fractured. C 3 months after open reduction, a Rush nail inserted across the fracture site (Curving of the nail allowed maintenance of the natural radial contour) Scar ring during the long period required for healing interfered with rotation and 1 year after frac ture supination was limited. D end result Patient returned to lighter work than that done before operation. Has moderate restriction of dorsiflexion and palmar flexion of the wrist Pro-nation one-half normal. Supination normal.

by screws alone has been sufficiently ımon to warrant the introduction of a ıe graft when plates or screws are used. ıen operation is delayed, bone should 'ays be added as a supplement to metal fixation.

Vhen an onlay graft is used the graft st be strong enough to hold the fracture ırely The proper length of a graft is taken from the iliac crest in cross-section It should be somewhat hemispherical in shape and it should be about 2½–3 inches long When excised, such a graft may be somewhat curved or irregular in shape but by trimming it can be made to fit closely to a forearm bone It provides a partly encircling contact of much greater extent than a flat graft, and its semitubular shape



ig. 251 —Nonunion of closed fracture following open reduction and inadequate internal ion. A the original fracture B 1 year after application of 2-screw plate to each bone :h did not give fixation C 2 years after injury and 1 year after the removal of plates and ws and the application of a thick iliac bone graft to the radius (held with 4 screws) and of bone slabs placed subperiosteally about the ulnar fracture There was complete return of :tion of the forearm.

ıt six times the diameter of the bone he fracture site and about two thirds diameter in width two screws should he graft to each fragment. In fractures oth the radius and ulna both bones are ıred

ither tibia or ilium yields a satisfactory t The technique for removing and apng bone grafts is described in Chapter on Operative Treatment of Fractures /hile at times a satisfactory flat graft be taken from the iliac wing often the ıgth of such a graft is inadequate and ay fracture A stronger graft may be gives it great strength (See Chapter 6 on Technique of Bone Grafting)

Metal plates have been used for years for fixation of forearm fractures but with far from constant success Failures have appeared to result from the use of too thin plates which have broken or from inadequate fixation by 2 or 3-screw plates or from too great reliance on the security of plate fixation during attempts at early mobilization of the broken forearm (Fig 251) Plates should be fixed by at least 2 screws to each of the major fracture fragments the screws should penetrate both cortices hold

ing firmly in each The composition of the screws must match that of the plate used If because of the contour of the fracture, these criteria cannot be met other means of fixation should be used The likelihood of failure from the use of metal plates will be great in fractures where comminution at the fracture site prevents a plate from providing rigid fixation

A satisfactory plate is the Eggers type fiber and catgut sutures and metal bands almost never provide adequate internal fixation

Medullary Nails in Forearm Fractures —Of the several intramedullary nails avail able the somewhat malleable Rush nail seems to be the best for use in fractures of the ulna and the curved radius In radial fractures the nail is introduced from the distal end on the dorsal side near the radial



Fig 252.—A, 1 year after fracture of radius was treated by open reduction and fixation by wire loops The fracture did not unite and absorption of bone occurred at the fracture site With shortening of the radius and subluxation of the distal end of the ulna severe disability resulted. There was fixed pronation deformity of 10 degrees B after application of an iliac crest graft fixed by 4 screws Restoration of 1 inch of radius length did not completely overcome ra dial deviation of the hand At follow-up after 10 months the patient was engaged in his nor mal occupation without restriction. Rotation of the forearm, however was limited to 25-degree pronation and 15-degree supination Flexion and extension of the wrist also were limited.

This plate is strong and when used with screws introduced properly it may allow coaptation of bone ends if absorption oc curs (Fig. 249) The use of metal plates should be accompanied by bone across the fracture site

Long oblique fractures are not usual in forearm bones and therefore it is rare for screws alone to give adequate fixation When plates and screws are used the arm must be held securely by plaster until bone union is firm

Encircling or suturing wires (Fig 252) styloid The point of introduction and the direction and shape of the nail must be ac curately selected for improper introduc tion of the nail especially in fractures of the lower radius can produce deformity and prevent healing The length of the nail must be adequate to hold the proximal fragment securely which ordinarily can not be accomplished by distal introduction in fractures of the proximal third of the radius (Fig 250)

In fractures of the proximal two thirds of the ulna a Rush nail may be introduced

from the proximal end (Fig. 253) In a fracture of the distal third of the ulna, the nail should be introduced distally and dorsolaterally about ¾ inch above the tip of the ulnar styloid (Fig 254)

In fractures of both bones both the radius and ulna should be fixed when nails are used With nail fixation of only one bone although at the time of operation the other bone may appear stable without internal fixation, the unfixed bone may angulate after several days Such angulation occurs as a consequence of the reduction of the slight distraction at the fracture site which is characteristic in forearm bones stabilized by Rush nails

Except in some fractures of the proximal ulna, forearm fractures treated by intramedullary fixation should be protected by plaster extending from the necks of the metacarpal bones to the axilla and holding the elbow at 90-degree flexion, until union is firm. When incompletely healed forearm bones are allowed to rotate the progress of solid union may be interfered with

It should be emphasized that, while the contour of the medullary canal of the ulna allows easy introduction of even a straight nail without deforming the natural shape of the bone this is not true of the radius. The narrow medullary space in the most curved portion of the radius will not receive any of the intramedullary devices available without some degree of straightening of the natural two-plane curve of the bone (Fig 256) and with the expected result of some loss of forearm rotation If the degree of loss is slight, the loss may be easily compensated by shoulder motion and for gross use of the arm and hand the loss may not



Fig 253 —Proper use of Rush nail to stabilize fracture of proximal ulna Left the original fracture. Right excellent progress of healing at 3 months Stability was adequate to allow early elbow motion

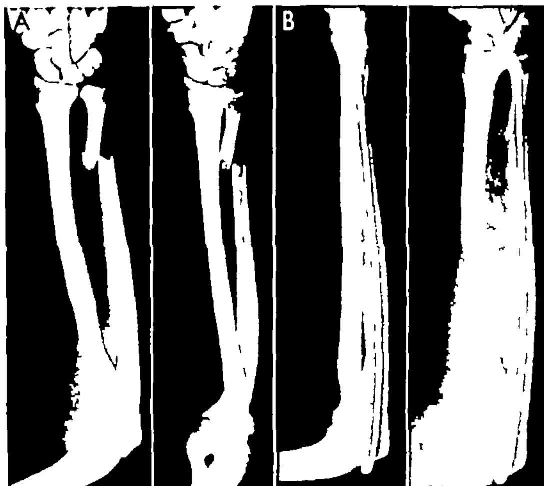


Fig 254 —Improper use of Rush nail to stabilize fracture of distal ulna A, the original fracture B insertion of a Rush nail from the proximal into the distal ulna gave inadequate fixation with loss of position Distal introduction of medullary fixation across fracture at this site should be done if the method is used

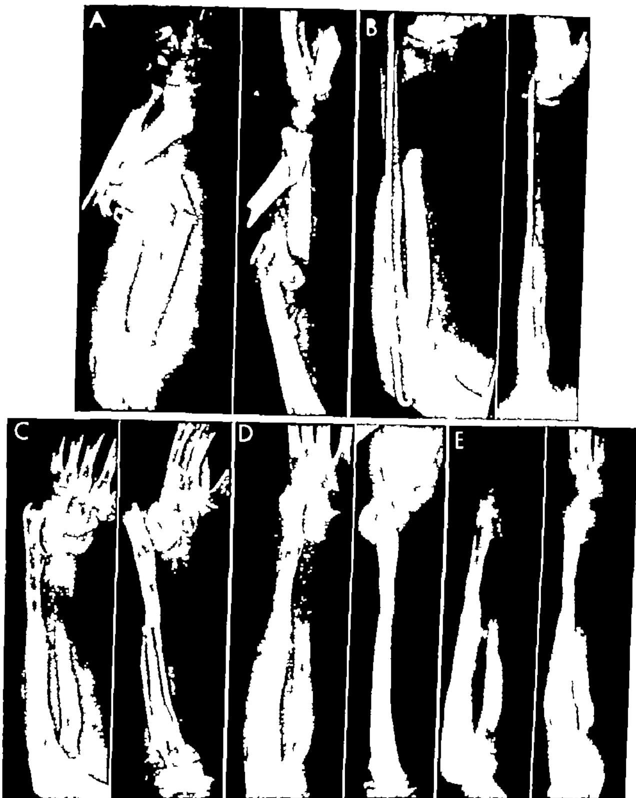


Fig 255 —A the original fracture Although there was massive damage of the soft tissues and intense soiling of bone which required resection of large fragments function and sensation of the hand were preserved well enough to justify its preservation. B instability of bone fragments during use of the hand interfered with healing of wounds Insertion of a Rush nail in the ulna at 8 weeks stabilized the forearm sufficiently to allow continuing hand exercises union of the ulna, and closing of skin C the ulna united The soft-tissue shadow of a full-thickness graft applied preparatory to radiocarpal grafting can be seen. Hand function is good. D an attempt to reconstitute the defect of the radius by the use of a tube of fibula stabilized by a

constitute a handicap to the patient However the ideal in treatment should be restoration of complete forearm rotation for a patient with special skills this is of great importance

Until the functional results of treatment of radial fractures by intramedullary devices have been evaluated in a larger number of cases this method can be recommended only in badly damaged forearms where full functional recovery cannot in any event be anticipated (Fig 255)

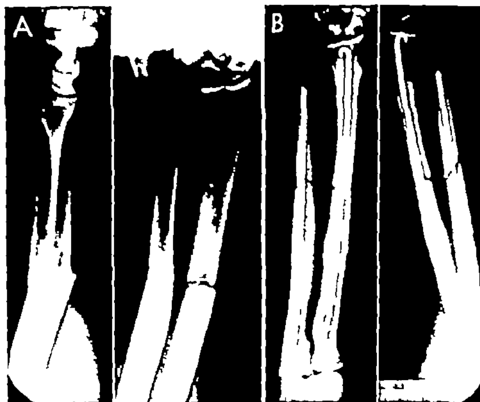


Fig 256 —A, simple fractures of radius and ulna unstable at closed reduction. B after open reduction with stabilization of both bones by Rush rods The normal curving contour of the radius has been lost.

Fractures of Radius with Dislocation of Distal Ulna

Fractures of the distal radial shaft with dislocation of the lower end of the ulna may result from a fall on the outstretched hand The distal ulna may project through the skin Because of rupture of the triangular ligament stable reduction is difficult to obtain Open fixation of the radius is frequently required (Fig 257)

In compound dislocations debridement and closure of the wound is ordinarily possible If the articular surface of the ulna is badly damaged and soiled resection of the distal end of the ulna will not interfere with functional recovery when the radius is reduced and held (Fig 258)

Open Fractures of Forearm

Open fractures of the forearm are treated according to the principles de-

Rush nail did not succeed This graft was removed, and the distal ulna has been inserted into the carpus with the expectation of fusion. E, end result after failure of the fibular transplant to the radius. The graft was removed through a separate incision from the ulnar side of the wrist. The distal end of the ulna was imbedded in the central portion of the carpus and fusion obtained.



Fig 257 —Distal radial fracture with dislocation of distal ulna treated by radial reduction A, the original fracture caused by a gunshot wound B during open debridement it was possi ble to replace the distal radial fragments in a position stable enough to maintain reduction o the ulnar dislocation



Fig. 258 —Compound dislocation of distal ulna with gross contamination treated by resec tion of ulna end. A, the original fracture Extreme soiling of distal ulna is apparent B radius fixation by a 4-screw plate and resection of the distal ulna. Functional recovery

scribed in Chapter 33 Treatment of Open Fractures—i e through debridement stable reduction of the fracture and wound closure achieved as promptly as possible

Internal fixation is employed only when stable manipulative reduction cannot be obtained but the clean open wound is not considered a contraindication to internal fixation If treatment is delayed for 6 hours extensive soft tissue damage or established infection when local wound treatment is required (Fig 259)

Nonunion of Forearm Bones

Nonunion of fractures of the radius and ulna is not uncommon Usually it results from inadequate reduction or insecure im

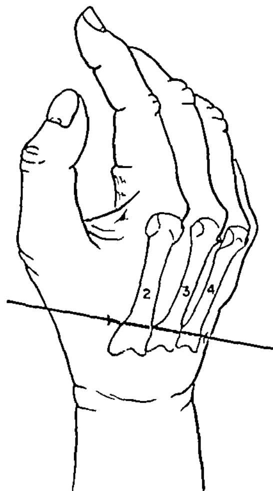


Fig 259 —In the unusual instances when skeletal traction is used in treatment of forearm fractures a Kirschner wire through the bases of the middle three metacarpals (2 3 and 4) avoids interference in hand exercises as well as scarring in the intrinsic muscles

or longer or if there is extensive soiling as in war wounds secondary skin closure may be indicated. *Where there is extensive soft* tissue damage and skin loss preventing wound closure or requiring too great tension to accomplish it primary skin grafting is done Bone grafts are not usually added in fresh open fractures The use of traction exerted through a Kirschner wire traversing the bases of three metacarpals can be employed in cases of open fractures with mobilization too early mobilization or unfortunate operation with the use of hardware which holds the bone ends apart (Fig 251)

Treatment of nonunion requires grafting of the fracture site After proper alignment of the fragments a strong cortical bone graft is fixed across the fracture site by 4 screws and the arm is incased by plaster until the union is firm (Figs 251 and 260)



Fig 257 —Distal radial fracture with dislocation of distal ulna treated by radial reduction. A, the original fracture caused by a gunshot wound. B during open debridement it was possible to replace the distal radial fragments in a position stable enough to maintain reduction of the ulnar dislocation.



Fig 258 —Compound dislocation of distal ulna with gross contamination treated by resection of ulna end. A, the original fracture Extreme soiling of distal ulna is apparent. B radius fixation by a 4-screw plate and resection of the distal ulna. Functional recovery

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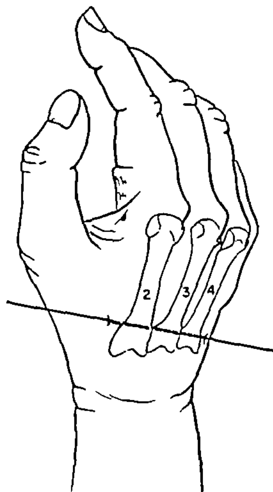


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Recently medullary nail fixation with cancellous bone placed across the fracture site has been preferred by some surgeons In old ununited fractures with consider able motion at the fracture site bone ends are likely to be distorted and malrotation may exist In such cases rotatory relationships should be established by x ray exami nation and proper alignment maintained by internal fixation, using a graft and screws Treatment requires osteotomy and graft ing Again because of distortion care must be taken to avoid fixing an osteotomized radius in a position of malrotation

Cross Union of Forearm Bones

Because of interosseous membrane contracture the treatment of cross-union of the radius and ulna very often ends in disappointingly little functional recovery even though recurrence of synostosis is avoided

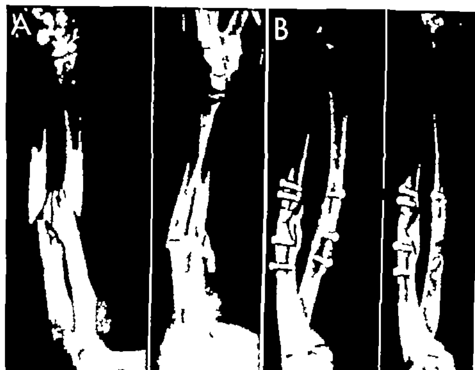


Fig 260 —A, 3 weeks after motorcycle accident in which fracture of the radius and ulna was received. Because of comminution stable closed reduction could not be achieved Apposi tion of the radial and ulnar fragments in the interosseous space makes synostosis a likely possi bility B open reduction and fixation of both bones by tibial grafts and screws Prompt union occurred and at 1 year the patient had normal function.

When cross-union affects the extremities of the bones which is unusual, resection of the distal ulna or of the proximal radius may be done Either procedure diminishes stability of the forearm but may result in improvement of rotation.

Synostosis affecting the shafts of the bones may be treated by resecting a wide segment of one bone along with the cross-growing bone followed by secondary graft

Occasionally fractures well reduced and well held by metal will unite slowly If there are no signs of pseudarthrosis at the frac ture site and if position has not deteriorated it may be assumed that healing will eventually become firm Healing can be accelerated by the simple addition of can cellous bone around fracture sites

Malunion of Forearm Bones

In adults malunion of fractured forearm bones is less common than nonunion



Fig 261 —Restoration of normal contour in a 14-year-old boy after reduction of midshaft radial and ulnar fractures in which the fragments were displaced but not angulated A, the original fracture B 6 weeks after stable reduction with moderate displacement In the lateral projection less than half of the fragment ends of the radius are apposed Linear alignment is good with no bow C 1 year after fracture Expected restoration of normal contour and normal function are found

ing after thorough soft tissue healing has taken place

Results of Treatment of Forearm Fractures at M G H

Of the forearm fractures in adults 62 per cent were treated by operation of these two thirds had functional results that were considered satisfactory Loss of rotation



Fig 262.—Persistent anterior bow of forearm bones in an 11 year-old boy after fracture at junction of middle and lower thirds of radius and of ulna in distal third A, 5 weeks after satisfactory reduction angulation apparent, but considered likely to be corrected rapidly during growth. B 1 year after fracture anterior bow persists C 3 years after fracture anterior bow limits pronation to 35 degrees

diminished the functional results of those considered unsatisfactory

Of the fractures treated by closed means 80 per cent were judged satisfactory It should be emphasized, however that this group of patients had less severe fractures.

Forearm Fractures in Children

In most forearm fractures in young children below the ages of 12 or 14 satisfactory reduction can be achieved traction and manipulation. Residual d formity after reduction may in some i stances diminish as growth procee Ordinarily slight over riding will not pe manently limit functional recovery (Fi 261) Depending on the level of the fra ture there is a considerable difference the amount of recovery to be expected fro angulation deformity Bow deformity of 1 degrees or more in the middle and upper thirds of the radius and ulna is likely to persist with some permanent limitation of rotation (Fig 262) while in the lower third a bow of even 35 degrees may be re duced during growth to a normal contour with recovery of normal function. This dif ference is evident through most of child hood that is a midshaft bow in a 6-year old child may be a permanent deformity while a more severe bow in the distal third affecting an adolescent with only a year or

so of growth remaining may in that year be reduced to a normal bone contour

GREENSTICK FRACTURE. — Because the cortical bone is less brittle in the young greenstick fractures of the forearm shafts are common Ordinarily these are the result of a twisting injury when the patient falls on the outstretched hand The distal forearm is fixed with the hand on the surface that the hand strikes and the proximal forearm either supinates or pronates to a degree sufficient to cause fracture of the forearm bones With a twisting of the extremity into supination the forearm is deformed with an anterior bow at the fracture site (Fig 263 A) The reverse of this deformity is caused by a pronating injury Occasionally only the radius is fractured (Fig. 263 *B*) In greenstick fractures simple manipulation by rotating the distal fragment on the proximal one will achieve reduction of the bow as well as of the rotatory deformity If the fracture can be reduced by rotation it is not necessary to immobilize the forearm in extreme pronation or supination to hold stable reduction The usual length of time required for plaster fixation is 6–8 weeks

In a greenstick fracture it is usually necessary to break the periosteum on the concave side in order to obtain complete reduction and stability of this fracture Otherwise recurrence of deformity is likely to occur

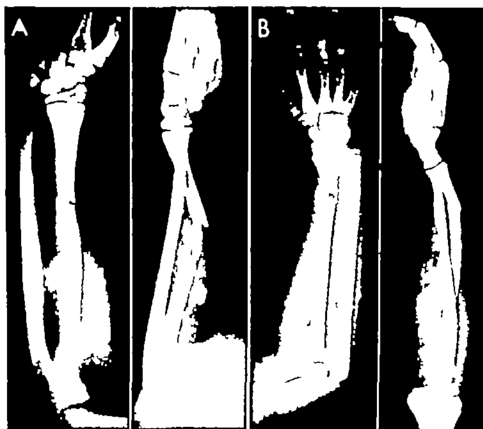


Fig 263 —Supination and pronation fractures A, a fracture of the distal radius of a 10-year old child caused by supination of the extremity on the hand B a greenstick fracture of the right arm of a 7 year-old girl, in which the extremity was pronated on the hand The fracture was reduced by supination of the hand.

As swelling about a fracture site subsides and as muscles atrophy the fixing plaster must be adjusted to insure that it fits the size and shape of the arm closely The more perfect the fracture reduction the less likelihood there is of displacement but even with the rapid healing of children loss in position of forearm fractures can occur as late as the third week after reduction if firm fixation is not maintained The

position of fragments should be examined by x ray frequently after reduction and if satisfactory position is lost remanipulation should be done promptly Either a circular cast or plaster splints bandaged to the arm may be used for fixation both of these forms of fixation should extend from the necks of the metacarpals to the axilla usu ally with the elbow flexed to 90 degrees and the forearm in the position of rotation in which *reduction is most* stable

REFRACTURE OF FOREARM *BONES IN* CHILDREN —Refracture of the radius and ulna in children is common especially so when reduction is incomplete After re*manipulation and* reduction plaster fixa tion must be prolonged for at least 8–10 weeks If acceptable reduction cannot be achieved and maintained by manipulation and plaster immobilization open treatment *should* be used. In general open reductions which are done early will result in better rotation than those which are carried out several months after fracture when it has become obvious that function is not ac ceptable (Fig 264)

Because *cortical bone in children is* rela tively pliable the irregular spicules of bone at the site of fracture are often not broken off and it is quite possible after open ex posure of the fragments to interdigitate the irregular ends of the bone and achieve sta ble reduction In such cases internal fixa *tion is not required If it is impossible to* achieve stable reduction at operation in ternal fixation should be used for this a firm cortical graft of tibia applied to the bone with 4 screws or a small 4-screw bone plate will be satisfactory When a plate is used additional bone from the tibia or the bone bank may be applied around the frac ture site Intramedullary rods which must be driven through epiphyses should not be used in children

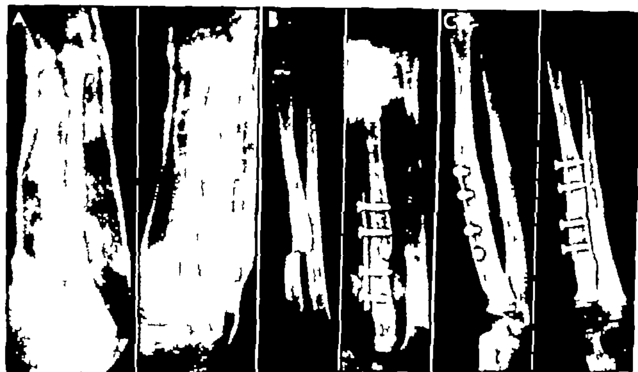


Fig 264 —Multiple refracture of *radius in a 5-year-old boy treated by tibial graft. A, the* original fracture reduced An incomplete fracture of the ulna is not clearly seen. The patient was followed elsewhere but was not seen until 11 months later He was said to have had refractures at 3 months and at 11 months B *nonunion at 11 months after initial fracture treated* by open fixation by a tibial graft and 4 screws C 1 year after operation Pronation was limited by 10 degrees Screws were removed 14 months after operation

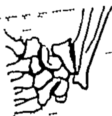
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21  Colles' Fracture

An irish surgeon Abraham Colles described a fracture of the distal portion of the radius in 1814 Since that time a fracture at that site has commonly been referred to as "Colles fracture" and although the original description referred to a fracture passing through the cancellous portion of the radius 4 cm above the articulation with the wrist joint the term has in recent times been used to designate fractures of various types—transverse oblique comminuted and those extending into the radiocarpal joint. This discussion will include all fractures of the distal 3 cm of the radius and the styloid process of the ulna. It does not include those fractures that involve the distal shaft of the ulna

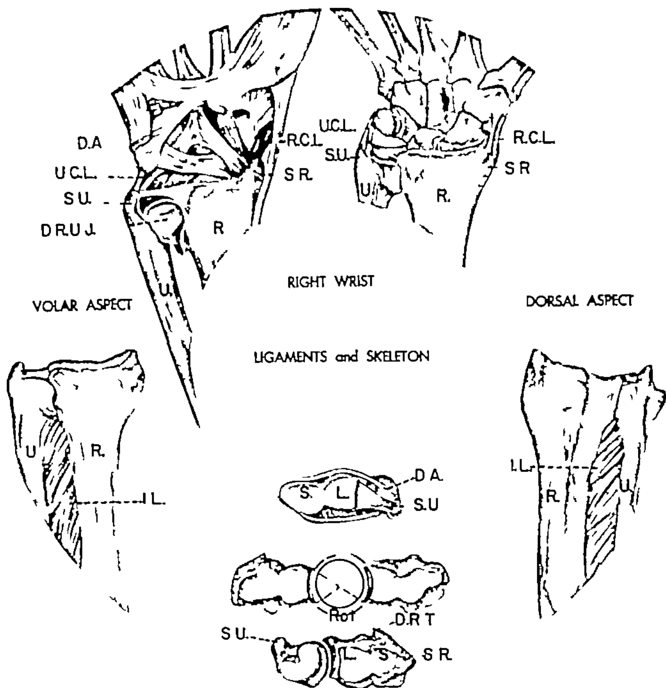
ANATOMY

The bones and ligaments of the wrist are diagramed in Figure 265 The lower end of the radius is broad and thick, with a large surface which articulates with the proximal row of the carpal bones The styloid process extends distally along the lateral aspect for a short distance The lower end of the ulna presents a cylindrical articular surface for about two thirds of its circumference This surface articulates with the sigmoid fossa of the medial aspect of the distal radius This articulation is made secure by the discus articularis or triangular ligament, which arises from the base of the short styloid process of the ulna and fans out and becomes attached to the edge of the sigmoid of the radius The distal articular surface of the ulna articulates, not with the wrist bones, but with the discus articularis The proximal row of the carpal bones articulates with the discus articularis and the distal surface of the radius but not with the ulna.

The wrist and hand are a prolongation of the radius which rotates about the fixed ulna, with the styloid process as the center of the arc of motion The primary motions of the wrist are pronation, supination dorsiflexion, palmar flexion radial deviation, and ulnar deviation The major part of this motion takes place at the radiocarpal joint, except for the rotatory movements of pronation and supination, which take place at the distal radioulnar joint.

The styloid processes of the radius and ulna are useful landmarks the radial styloid being readily located on the lateral aspect of the wrist lying approximately 1 25 cm distal to the ulnar styloid, which is prominent on the medial side of the wrist Any alteration of this relationship of the styloids is an aid in the diagnosis of a fracture of this region.

The radial and ulnar collateral ligaments extending from the styloid processes distally to the carpus and metacarpus give



Ligaments—Volar Aspect

U C.L.—Ulnar collateral ligament
R.C.L.—Radial collateral ligament
I.L.—Interosseus ligament
D.R.U.J —Distal radioulnar joint
D.A.—Discus articularis

Distal Extension of Radius and Ulna

S —Articulation of scaphoid
L.—Articulation of lunate
D.A —Discus articularis
Rot.—Rotation of radius around ulna
S U —Styloid process of ulna
S.R.—Styloid process of radius
D.R.T —Dorsal radial tubercle

Skeleton—Dorsal Aspect

U —Ulna
R.—Radius
S U —Styloid process of ulna
S.R.—Styloid process of radius

Fig 265 —Anatomy of wrist

stability to the wrist. Tendons from the flexor and extensor muscles of the wrist, fingers and thumb also lend support to the bone structure These tendons are intimately associated with the surfaces of the radius and ulna at the wrist and although rarely may be involved in fractures in this region. Likewise the adjacent vessels and nerves may be involved, the median nerve and the extensor pollicis longus tendon being most commonly but rarely injured.

MECHANISM OF INJURY

A fall on the outstretched hand is the usual cause of a Colles fracture and although other injuries to the hand wrist, elbow and shoulder may occur a fracture of the distal radius with or without a fracture of the ulnar styloid process is much the most common injury from a force of this type

The impact of a fall on the outstretched pronated hand is transmitted through the base of the hand to the carpal bones chiefly the navicular and thence to the broad articular surface of the radius. This surface is strong and often remains intact with a fracture occurring 1 5–2 cm proximally in the weaker cancellous portion of the bone The displacement may be minimal, but more often an obvious deformity results Impaction takes place with shortening dorsal angulation and supination of the distal fragment. If the force continues varying degrees of comminution occur in the distal fragment. *The older the individual, the more severe the fragmentation is likely to be*

A disruption of the radioulnar joint takes place if the wrist becomes widened and there is an appreciable amount of dorsal angulation and posterior displacement of the distal radial fragment. The triangular ligament (discus articularis) may be ruptured or avulsed from its attachment to the radius or ulna with or without a fragment of bone The loss of this stabilizing structure may allow the hand and carpus to be separated from the ulna and become dislocated posteriorly in relation to the head of the ulna.

DIFFERENTIAL DIAGNOSIS

A typical deformity results from the type of injury and pathological changes which have just been described. This is the so-called "silver fork" deformity (Fig. 266) so designated because the wrist and hand tend to assume a forklike appearance, owing to the posterior displacement and angulation of the distal radius and hand. There is a humplike mass over the dorsum

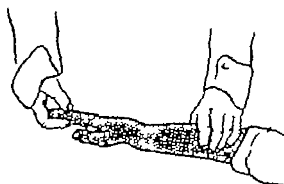


Fig 266 —Diagram of silver fork deformity

of the wrist the hand and wrist appearing to be displaced or dislocated posteriorly The usual straight line of the dorsum of the radius and hand is lost and the normal volar concavity of the radius is also lost The prominence of the ulna which is seen dorsally in the normal wrist disappears with this posterior displacement of the distal radius and hand. The relationship of *the styloids is altered the radial styloid* being definitely less than a centimeter distal to the ulnar styloid and in some instances on a parallel or even a more proximal plane Swelling and ecchymosis usually occur the swelling being more marked dorsally and the discoloration more evident on the volar surface of the wrist. There is as a rule a fairly marked loss of function of the wrist and hand and, although some movement is possible all motions are accompanied by pain. The ability to flex and extend the fingers is usually preserved but such movement is limited by pain and

swelling There may be a generalized complaint of numbness of the fingers and thumb but sensation is likely to be intact In a rare instance there may be loss of sensation usually over the distribution of the median nerve in the hand Even more rarely motor function of the intrinsic musculature is disturbed Acute and localized tenderness over the dorsum of the wrist at the point of angulation is always present Crepitus is usually absent because the fragments are impacted and there is little or no motion between them A simple crack or minimal impaction of the distal radius might produce all of the foregoing signs except for the deformity

The silver fork deformity is also present in other injuries—for example separation of the distal radial epiphysis which occurs in young persons who experience a similar type of trauma The diagnosis is evident only on x ray examination

X RAY EXAMINATION

X ray films of the injured wrist should be taken in anteroposterior and lateral views and should include the wrist and the elbow joints.

When fracture of the shafts of the distal radius and ulna occurs within 2 or 2 5 cm of the wrist joint a typical silver fork deformity may be present and the findings may be essentially the same as those of the Colles fracture except that there is no distortion of the positions of the styloids of the radius and ulna and the distal radioulnar joint remains intact A definite diagnosis again rests on the x ray examination

Another but much less commonly seen injury which simulates this deformity is that of a retroulnar dislocation of the carpal bones (Fig 267) This may occur with or without a fracture of the carpal navicular A patient with a silver fork deformity and no evidence of fracture by x ray films probably has a dislocation of the carpal bones and the films should be carefully examined for this injury because it is occasionally undetected. A comparison of such x ray films with those of a normal wrist is often of value in establishing a definite diagnosis It is very important to include in the examination an inspection of the elbow and shoulder for associated fractures which often occur with this type of injury

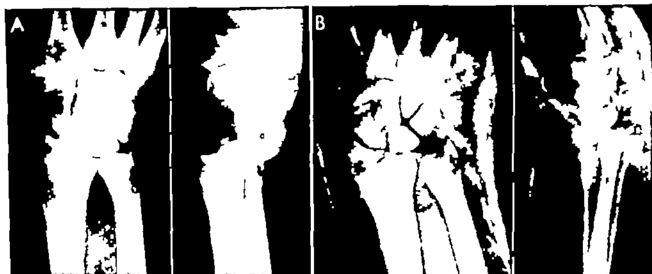


Fig 267 —A fracture of radial styloid with dislocation at radiocarpal joint, producing typical silver fork deformity B after reduction of fracture and dislocation

ASSOCIATED INJURIES

A number of bone injuries involving the wrist elbow or shoulder may accompany a Colles type of fracture depending on the





Fig 268 —A comminuted Colles fracture with fracture of the carpal navicular B reduction in plaster C healed fracture of radius and healing fractured navicular with graft in site (graft done because of nonunion of the navicular)

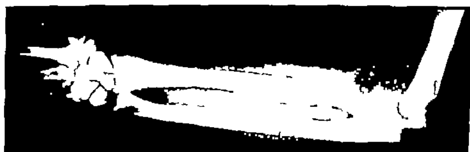
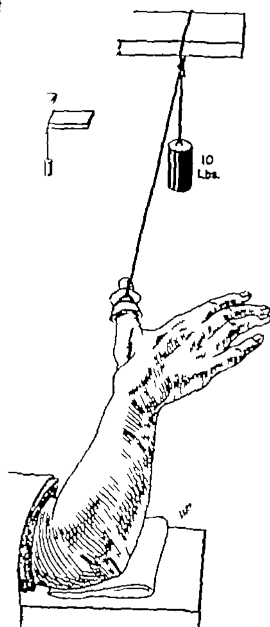


Fig 269 —Colles fracture with fracture of the radial head



Fig 270 —A, [illegible] fracture of d[illegible]

quate muscular relaxation of the ex
mity is necessary if the surgeon is to
stablish normal anatomical relation
ps at the fracture site (Fig 272 C)
The choice of anesthesia is therefore im



dissipation of the force In the wrist the navicular bone (Fig 268) which articulates with a sizable portion of the distal radius may be fractured as the force of the blow is distributed from the hand to the wrist and thence to the forearm bones through the forearm to the proximal portion of the radius at the elbow joint if the elbow is held firmly in an extended position Or the force may continue across the joint to the distal humerus where the inter or supracondylar regions may be frac



Fig. 272.—A, typical Colles fracture with impaction dorsal angulation of distal radial fragment fracture of ulnar styloid, and disruption of distal radioulnar joint. B after reduction with plaster fixation slight radial deviation of the hand and distal radius persists C healed fracture 1 year later showing good alignment except for a slight radial position of the wrist and distal fragment and an ununited ulnar styloid

tured (Fig. 270) Lastly the force may carry more proximally to the head and neck of the humerus usually resulting in an impacted fracture of the surgical neck of this bone (Fig 271) Dislocations also occur at the elbow and shoulder as complications of the Colles fracture.

The navicular fracture may be undetected and may heal during the course of treatment of the radial fracture As many as 5 per cent of the distal radial fractures are complicated by navicular fractures

A fracture of the radial head (Fig 269) results when the force is transmitted

TREATMENT

Once a definite diagnosis has been es tablished (Fig 272 *A*) treatment is planned If little or no deformity exists the wrist is immobilized in slight palmar flex

Adequate muscular relaxation of the ex tremity is necessary if the surgeon is to re-establish normal anatomical relation ships at the fracture site (Fig 272 C)

The choice of anesthesia is therefore im

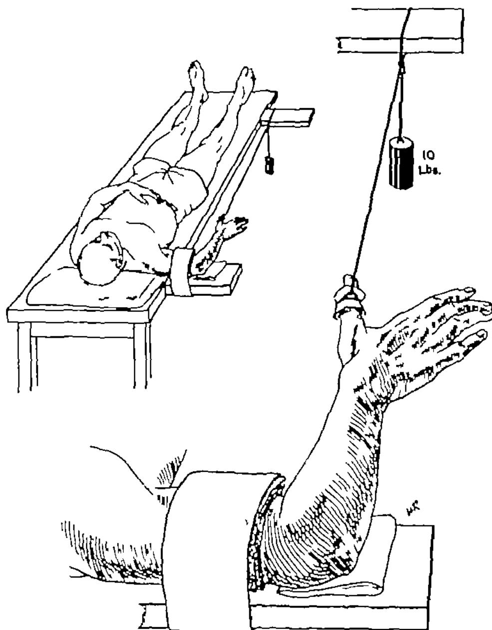


Fig 273 —Method of thumb traction for reduction of Colles fracture (From Cave E. F Injuries to the wrist joint, Am. Acad Orthop Surgeons 10 1 J W Edwards Inc Ann Arbor Mich 1953)

ion and ulnar deviation by means of plaster splints (Fig 272 *B*) When there is appre-ciable deformity a reduction of this de-formity should be carried out if the patient s general physical condition is satisfactory

portant and as a rule some form of gen eral anesthesia—such as *ether nitrous* oxide or Pentothal® sodium—is desirable In some instances a general anesthetic is not possible and relaxation must be ob-

tained by other means—either local anesthesia into the site of fracture or prefer ably a brachial block anesthesia. Local anesthesia has been used at the Massachu setts General Hospital in rare instances with undesirable results in that adequate relaxation is usually not obtained and the reductions are therefore less satisfactory Brachial block has been used with increasing frequency during the last decade and has been found to be a very desirable anesthesia with few complications

Reduction of the fracture is done when to apply traction either manually or by means of an apparatus such as that shown in Figure 273 When manual traction is applied, it is usually done by grasping the hand and pulling forcefully in the line of deformity and applying countertraction to the arm with the elbow flexed The traction is maintained in the direction of the de formity gradually bringing the hand into a position of palmar flexion, ulnar devia tion and pronation (Fig. 274) In most instances when steady traction is used for a few moments the impaction is sufficiently

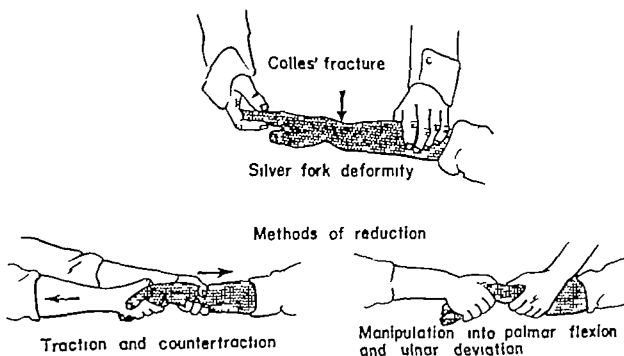


Fig 274 —Manual method of reduction

the patient has been adequately relaxed by the anesthesia of choice The reduction and establishment of satisfactory relationship of the fractured fragments depends on several factors first a disruption of the im pacted surfaces to establish mobility at the fracture then correction of posterior displacement and dorsal angulation of the radius with restoration of radial length This should bring about a proper relationship at the distal radioulnar joint with a dorsal position of the ulna and the re-establishment of the volar concavity of the radius

To bring about reduction it is necessary broken up so that this maneuver brings about a fairly normal relationship of the fragments If the hand is held in the posi tion of ulnar deviation and a moderate degree of palmar flexion the position will be maintained It is probably wise to bring the hand through a full range of palmar flexion and then reduce the palmar flexion to a moderate degree maintaining ulnar devia tion X ray films should be taken at this point to be sure that a satisfactory reduc tion has been accomplished (Fig 272 *B*) The normal volar concavity should be restored and the relationship of the radial cortices particularly the volar cortex,

should be relatively smooth The distal fragments should no longer be in dorsal position and the normal angle of the radio carpal joint should be slightly (10–15 degrees) volarward (Fig 275) If x ray ex

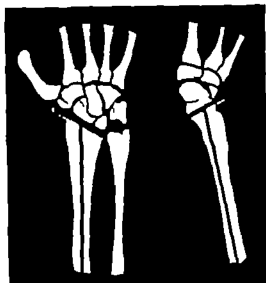


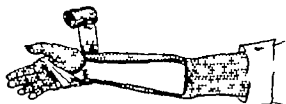
Fig 275 —Diagrammatic sketch showing the normal degree of palmar tilt of the articu lar surface of the radius in the anteroposterior view and in the lateral view

amination shows that this relationship has been established and the styloid of the radius is distal to the styloid of the ulna by 1 cm or more and the radioulnar joint is in good relationship the hand and wrist should be immobilized in splints

The splints should be of plaster of paris with a layer or two of sheet wadding be tween the plaster and the skin One splint should be molded carefully to the dorsum of the wrist and hand extending from the metacarpophalangeal joints to just below the elbow the second splint should extend from the distal palmar crease of the hand on the volar surface along the wrist and forearm to below the elbow allowing suffi cient room for flexion and extension of the elbow (Fig 276) These splints are held in position by means of a gauze bandage wrapped around the arm and by splints extending from the distal palmar crease through the web space between the index finger and thumb to just below the elbow While the splints are being applied and while they are setting traction should be maintained on the thumb or fingers with the hand in the corrected position of palmar flexion ulnar deviation and pronation Once the splints have set properly x ray films should again be taken to be sure that the correct position has been maintained If position has been lost remanipulation should be carried out at this time removing the splints and carrying out the same maneuver—perhaps more forcefully depending on the x ray find ings

If the operator elects to use the thumb-traction method of reducing the fracture reduction can be done very satisfactorily with the apparatus shown in Figure 273 A 10-pound weight is applied to the thumb with the forearm in the line of the traction the arm being fixed with the elbow flexed. Usually traction of about 10 pounds for 10 minutes is adequate to bring about





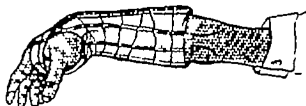


Fig 276 —Plaster splints applied after cor rection of the deformities to maintain position

disimpaction of the fragments and restora tion of the length of the radius

Before applying splints it is necessary to palmar flex the wrist by applying for... up ward beneath the radius in the region of the fracture Some slight molding of the

fragments with the thumb and fingers may be necessary Once the deformity has been overcome the maintenance of slight pressure beneath the volar aspect of the radius should be continued while the plaster splints are applied as described above

When the plaster has set, the traction is removed and the arm placed at the side in a sling When satisfactory reduction has been obtained and confirmed by x ray examina tion it is probably wise to apply a compres sion bandage to the thumb and fingers which remain free so as to prevent exces sive swelling due to the splints proximal to the fingers and thumb If sheet wadding and Ace bandage are applied around the fingers and thumb for 12–24 hours little or no swelling will occur in the fingers and early active function is thereby facilitated The tips of the fingers and thumb must be left free so that the circulation and sensa tion can be checked at regular intervals

After the reduction and fixation of the fracture the patient is instructed in exer cises which he must carry out regularly several times during the day He should put the fingers through a full range of flexion at each interphalangeal and meta carpophalangeal joint and should appose the thumb to the tips of the fingers and base of the fifth finger a number of times on each occasion The elbow should be flexed and extended through a painless arc regularly each day The shoulder should be put through a full range of motion a num ber of times daily to prevent adhesions and bursitis in the shoulder which are likely to occur in any elderly patient whose arm is maintained in a sling for more than a few days without exercising The sling should be worn for several days until the acute pain and swelling have subsided and there is satisfactory function of the fingers and elbow The sling can then be discarded for a greater part of the time

The period of immobilization in the splints varies from 4 to 6 weeks the aver age being 5 weeks the length of immobili zation depending to a considerable degree on the amount of comminution of the frag ments If a position of very marked palmar flexion and ulnar deviation is necessary to maintain proper alignment of the fragments it may be necessary to reduce this extreme position after 10–14 days to allow better function of the fingers and thumb. This is particularly true in elderly persons, who after long immobilization are subject to stiffening of the joints with inability to use them It is probably better to sacrifice position of the fragment and to preserve function of the fingers and avoid a prolonged period of rehabilitation. It is customary to bring the wrist out of the palmar flexed position after 2–3 weeks and to continue immobilization in a neutral position, so far as flexion and extension are concerned but maintaining the ulnar deviation. At the end of the immobilizing period (about 5 weeks) the splints are removed and x ray films are taken with the plaster removed to determine the degree of bony fixation Although the union may not be bony it is usually sufficiently firm at this period so that gentle exercises can be initiated. Then the anterior splint is reapplied and held in place with a supporting bandage. The patient is instructed in exercises for which the splint and bandage are removed two or three times daily during which time the arm is soaked and actively exercised. This treatment is continued for a week to 10 days after which the splint is discarded and the bandage is used alone for another week, the bandage being discarded as function and strength return It is not uncommon for the patient to have some persistent discomfort in the wrist, particularly in relation to the distal ulna. Such discomfort may result from nonunion of the ulnar styloid but it is more likely to result from some slight mal alignment of the distal radioulnar joint (Fig. 272 C) with complaint on prona tion and supination for several months.

Prognosis

The prognosis in the usual Colles fracture is good so far as function of the hand and wrist is concerned but it is not uncommon to find some residual deformity

which results either from loss of position while in the splint or from failure to obtain an adequate reduction The deformity which remains is usually one of some radial shortening with prominence of the distal ulna and a radial position of the hand Occasionally some slight posterior displacement persists Angulation of the articular surface of the radius is a common deformity instead of the usual palmar tilt of 10–15 degrees the articular surface is perpendicular to the radius or angulated dorsally In a series of 20 Colles fractures with satisfactory functional end result x ray examination showed evidence of some slipping or loss of palmar tilt in every case The slipping occurred while the arm and wrist were in plaster splints Little or no slipping occurred after the splints were removed The amount of slip ranged from 5 to 21 6 degrees the average being 11 7 degrees. Similar findings have been reported by others.

Operative Treatment

The operative treatment of Colles fracture is rarely used. Open reductions (Fig 277) were done six times in a series of 500 cases at the Fracture Clinic of the Massachusetts General Hospital or 1.2 per cent of the total number of cases When open reduction is carried out some internal fixation is often used to maintain alignment although sometimes it can be maintained by use of bone grafting In the operative treatment of Colles fracture it is probably wise to postpone treatment for several weeks until the main fragments are consolidated rather than to attempt manipulation of the multiple comminuted fragments When the fragments are consolidated then it is possible by doing an osteotomy in the region of the fracture to open the fracture site and to replace the fragments as nearly as possible and fill the defect with bone either a graft from the ilium or occasionally a graft from the ulna which may be prominent and which might be improved by partial removal of its distal portion (Fig. 278) The after-care in these operative procedures is essentially the same as that in the closed fracture although immobilization is sometimes continued a little longer

When compounding occurs which is also rare operative treatment is indicated This type of injury was present in 8 cases out of the series of 500 or 1 6 per cent In most instances after debridement and suture of the wound the fracture was treated as a closed fracture, with manipulation and application of external fixation Internal fixation was used rarely



Fig 277 —A comminuted Colles fracture after attempted closed reduction with unsatisfactory position B open reduction and internal fixation with a Kirschner wire and plaster splints

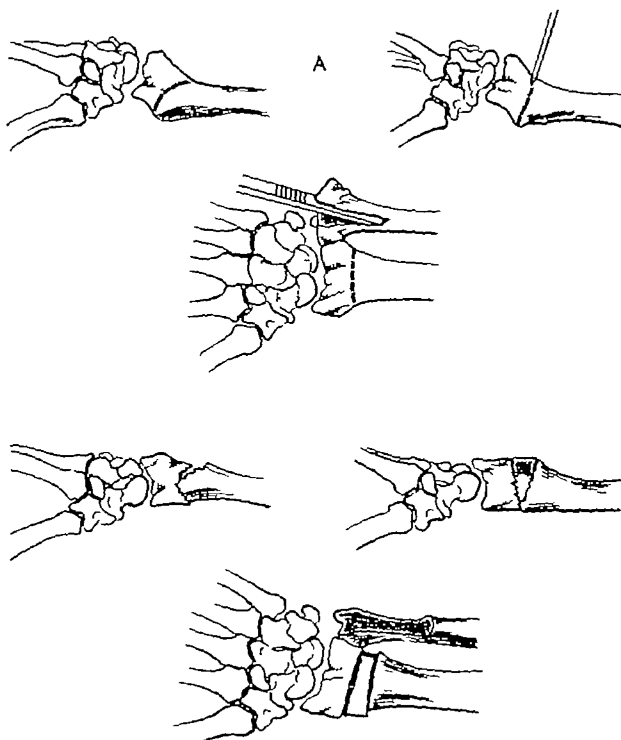


Fig 278 —A, drawing of an open reduction of malunited Colles fracture with the use of a portion of the distal ulna as a graft (*continued*)



Fig 278 (cont) — B roentgenogram of typical Colles fracture C healed in malposition 6 months after injury with symptoms of median nerve irritation D x ray view in plaster following open reduction and insertion of wedge graft. E 4 years after open reduction Dorsal displacement has been corrected Median nerve symptoms have been relieved but there is still some radial shortening

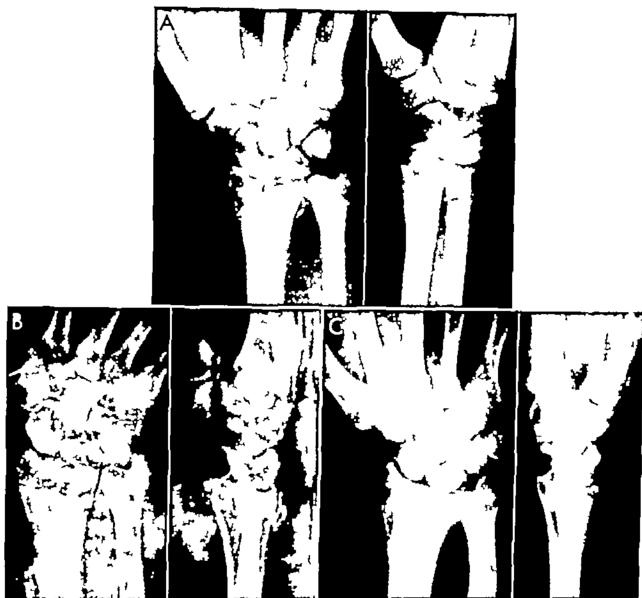


Fig 279 —**A**, comminuted Colles fracture with involvement of the radiocarpal joint. **B** reduction and fixation in plaster **C** 1 year later Healed fracture with good alignment (except for slight dorsal tilt of the radius) but a suggestion of narrowing of the joint space which is likely to occur from arthritic changes due to the fracture involving the radiocarpal joint.

Fractures of the distal radius which show marked comminution (Fig 279) can frequently be reduced satisfactorily by the usual methods of manipulation but it is often impossible to maintain this reduction with the usual splinting or casing because any external fixation which is sufficiently firm to prevent displacement is likely to cause pressure and complications It is therefore necessary to consider other means of fixing this type of injury to pre

Another type of fracture of the distal radius which is very likely to require continuous thumb traction to maintain reduction is the reversed Colles fracture or Smith s fracture (Fig 280) This is caused by a fall on the dorsum of the hand or wrist producing an oblique fracture of the distal radius with volar displacement of the fragments The deformity can in most instances be reduced by traction on the hand and thumb followed by dorsiflexing



Fig. 280 —A, anteroposterior and lateral views of reversed Colles or Smith s fracture B skeletal traction with Kirschner wire through thumb metacarpal.

vent deformity The reduction can be maintained in most instances by continuing the traction on the thumb This is done by introducing a Kirschner wire into the distal portion of the first metacarpal (Fig 280) and applying elastic traction to this skeletal fixation over an extension which is attached to the casing (Fig 281) When this type of traction is necessary the plaster casing should extend to just below the axilla with the elbow in 90-degree flexion In such a case the traction should be continued for a period of 4 or 5 weeks following which it is removed but the wrist is maintained in the plaster casing for another week or 10 days The casing is gradually discarded and the wrist mobilized

the wrist and immobilizing it in this position with plaster splints

If follow up x ray films reveal loss of position the reduction should be repeated and traction applied through the thumb as described above for the badly comminuted fracture with dorsal angulation.

Complications

The most common complication in the treatment of Colles fracture is some loss of position after reduction (This has been discussed on p 368 under Prognosis)

Another rather common and disturbing complication is stiffness of the fingers which results from swelling and pain and

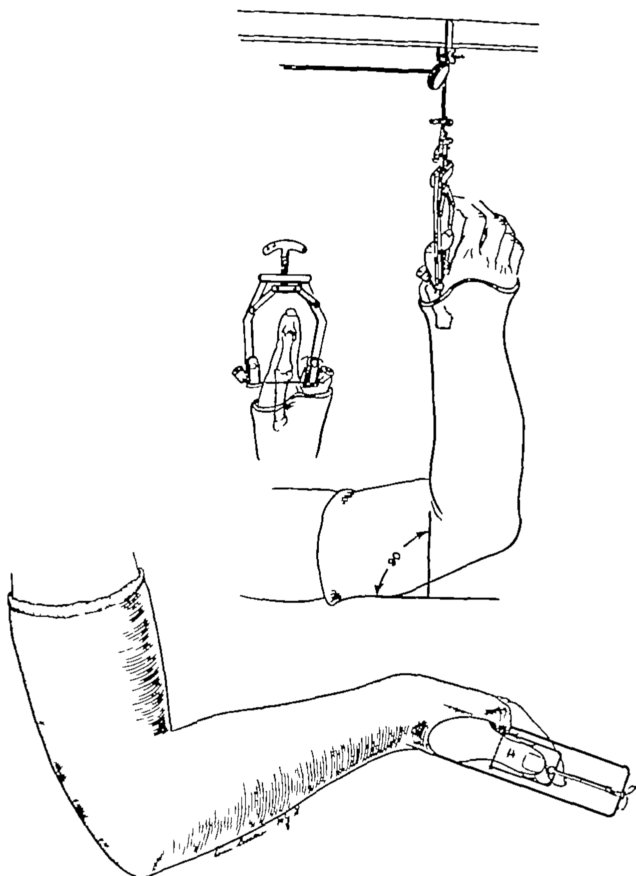


Fig 281 —Diagrammatic sketch of skeletal thumb traction in treatment of Colles fracture **Top** suspension in bed (From Cave E. F Injuries to the wrist joint Am Acad Orthop Surgeons Lect. 10 1 J W Edwards Inc., Ann Arbor Mich 1953) **Bottom** an extension attached to the cast, used in skeletal fixation.

22  Injuries to the Carpal Bones

Fractures and dislocations of the carpal bones comprise approximately 2 per cent of all fractures and dislocations treated at the Massachusetts General Hospital The

TABLE 13 —Types of Injuries in a Series of 186 Carpal Bone Injuries at the Massachusetts General Hospital

Fractured navicular	
Recent without other carpal injuries	56
Old (4+ mos) without other carpal injuries	41
With other carpal injuries	18
Dislocated lunate	13
With other carpal injuries	6
Retrolunar dislocation of capitate bone	14
Fractured lunate bone	5
Kienböck s disease of the lunate	9
Miscellaneous fractures including chip fractures	21
Cyst of lunate bone	1
Cyst of navicular bone	1
Congenital fusion of triangular and lunate bones	1
Total	186

injuries occur most commonly in the late teen-age and early adult group whereas Colles fractures are more frequent in the middle-aged and older group Carpal injuries are common in males and extremely uncommon in females owing undoubtedly to the trauma to which males are subjected The usual cause is a fall or blow on the dorsiflexed hand Of all the carpal injuries (see Table 13) the commonest are in order of frequency fracture of the navicular bone dislocation of the lunate bone and retrolunar dislocation of the capitate bone with rotation or fracture of the navicular bone (transcarpal dislocation) Other injuries occur much less frequently Chip fractures of the dorsum of the lunate capitate or other carpal bones are rather frequent but usually they do not cause severe disability or require prolonged treatment. The symptom is pain in the wrist joint and the signs are swelling, limitation of motion and tenderness localized to the particular bone injured The diagnosis is based on a history of the fall local examination, and—above all—properly taken x ray films.

DEVELOPMENT OF THE CARPUS

The carpal bones usually develop according to a definite plan and anatomical variations are infrequent The bones are cartilaginous at birth and during the first year the ossification centers of only the capitate and hamate bones appear The remaining centers are visible by x ray between the second and eighth years, except

ANATOMY

A thorough knowledge of the anatomical arrangement of the carpal bones (Figs 282 and 283) is essential to the surgeon who expects to treat carpal injuries Indistinct fractures and subluxations are frequently overlooked not through failure to take roentgenograms but through the surgeon s lack of knowledge of the anatomy of the parts in various positions of the hand The surface of the bones in the first row of the carpus consisting of the navicular lunate triangular and pisiform bones is largely cartilaginous The remaining portions of the surface serve for ligamentous attach ments The second row made up of the greater and lesser multangular bones and the capitate and the hamate bones is less cartilaginous but is more extensively cov ered by the ligamentous attachments This row is more firmly held together by the supporting ligaments than are the navicu lar and lunate bones which are more ex posed to trauma because of their location and their movable articulations with the radius On the volar surface there are ten-dinous attachments only to the pisiform hamate and greater multangular bones on the dorsal surface there are no attach ments The navicular bone articulates on its dorsal surface with the radius the greater and the lesser multangular bones and the lunate bone On its volar surface the navicular is in contact with the greater and the lesser multangular bones the capitate bone the lunate bone and the radius.

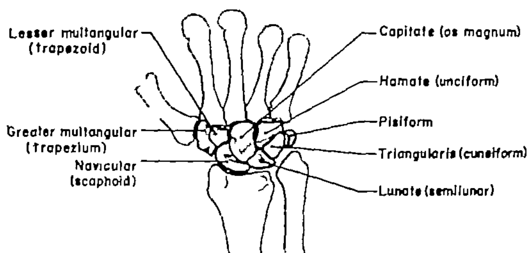


Fig 283 —Anatomy of carpus

DIAGNOSIS BY X-RAY EXAMINATION

The hands may be placed in so many varied positions that in the roentgenogram the bones may appear to have an abnormal relationship If the anteroposterier view of the navicular bone is made with the wrist in radial deviation, the bone may appear shortened or subluxated whereas with the wrist in ulnar deviation the true long axis of the bone is visible and any abnormality is more easily seen. It is important, therefore, not only to have standardized methods of roentgen technique but also to have adequate knowledge of the relationships of the carpal bones in the various positions of the hands For studying the carpal bones both hands should be photographed on the same plate

Routine anteroposterior and lateral views of the wrist joint are not sufficient to make a diagnosis of a fracture in the navicular bone Because of the overlap of one bone upon the other in the lateral view and the change in relationship of the carpal bone in the anteroposterier view special positions are necessary The following views are required (Fig 284):

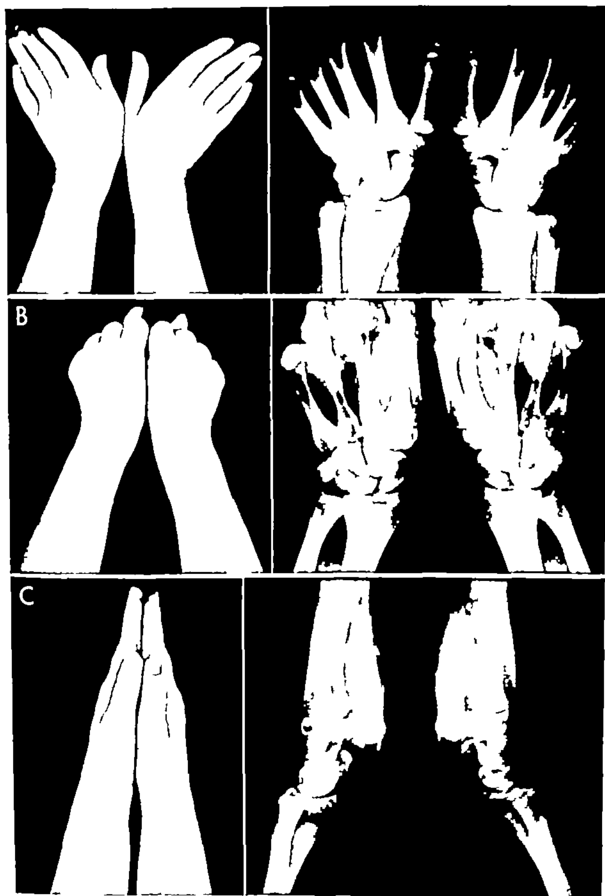


Fig 284 —Position of hands for x-ray of carpus with accompanying x ray views A ulnar deviation. B clenched fist C, lateral (continued)

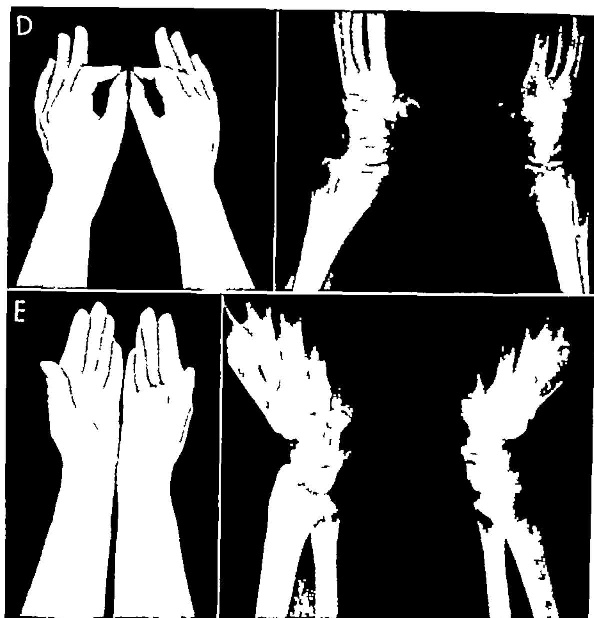


Fig 284 (cont) —D oblique E midsupination

1 Posteroanterior view with hand in extreme ulnar deviation. (At times this is not feasible because of pain.)

2. Oblique view with thumb and forefinger together and remaining fingers resting on the film.

3 Posteroanterior view with fist closed

4 Direct lateral views

5 Midsupination view with plane of the palm at an angle of 45 degrees to the film

Views taken with the wrists in extreme supination may occasionally be of value but very often the acute stage of the injury makes it impossible to place the wrist in this position.

TREATMENT

Fresh Navicular Fractures

Fracture of the navicular is by far the commonest carpal injury (see Table 13)

When any bone is fractured, the blood supply to the fragments is temporarily interrupted but this is particularly true of the carpal navicular bone (Fig. 285) If the fracture line runs directly through the bifurcation of the main artery which enters

the midportion of the navicular bone nutrition to the proximal fragment is interrupted the distal fragment is nourished however by the artery entering the tubercle Such interference with the blood supply to the proximal fragment explains the failure of union in a large percentage of navicular fractures in the middle and

The navicular usually fractures through the waist of the bone or at the junction of the proximal and middle thirds Displacement is as a rule not great and the only treatment indicated is plaster immobilization with the wrist in a neutral position The plaster should include the proximal phalanx of the thumb and should run from

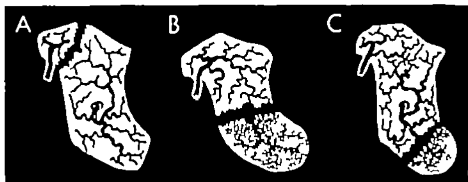


Fig 285 —Diagram showing interruption of circulation in navicular fractures A, fracture through the tubercle or distal portion of the bone is favorable for union because each fragment has a nutrient artery B and C fractures through central portion or proximal third are very slow to unite because the proximal portion of the bone usually has no nutrient vessel

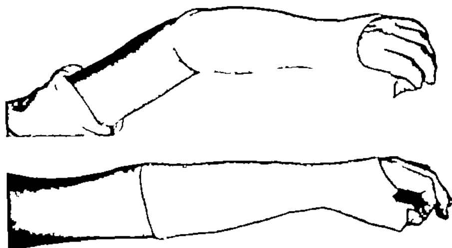


Fig 286 —Plaster immobilization for navicular fracture including thumb in position for grasping

proximal regions if prompt treatment is not initiated If immediate reduction and fixation are carried out there is usually restoration of blood vessels across the fracture line If treatment is delayed a scar forms and the blood channels are sealed off Even after several weeks have elapsed, it is possible to promote blood supply to the fracture if immobilization is carried out for a sufficient length of time

the palmar crease to just below the elbow (Fig 286) If the diagnosis of fracture is made early and immobilization is instituted at once a high percentage of these fractures will unite within 10–16 weeks The plaster should be renewed at 4-week intervals and x ray films should be made each month to determine whether or not union is present. This opinion must be based entirely on the roentgenogram (Fig. 287)

Nonunion of the Navicular Bone

In cases of prolonged nonunion of the navicular a reasonable form of treatment is a dowel graft directed from the distal to the proximal fragment (Fig 288) Following this operation the lesion is treated as a fresh fracture and immobilization is pro-

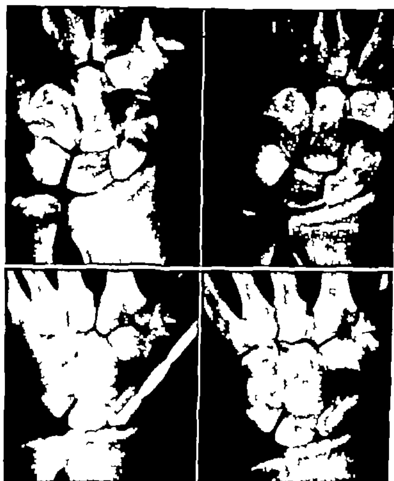


Fig 287 (top) —*Left* delayed union of navicular bone fractured 5 months previously Note same density of two navicular fragments indicating maintenance of circulation to both. *Right* healed fracture 4 months after immobilization in plaster of paris

Fig 288 (bottom) —Technique for inserting tibial graft for ununited navicular *Left* drill in position. *Right* tibial graft inserted from distal fragment into proximal fragment

longed until union is complete If there is an associated extensive traumatic change in the wrist joint, along with the fractured navicular wrist fusion may be the acceptable form of treatment. In old cases excision of the navicular and the lunate does not give a satisfactory result and this operation is to be condemned. *Böhler stated*

I have never seen a case in which the usefulness of the hand has returned to normal after removal of the navicular bone Kemper has collected 60 cases of removal of the navicular *and lunate bones in all of these*, function of the hand was poor In cases operated on early the mobility of the wrist may remain good but the strength of the hand is always weakened.

Barnard has advised removal of the radial styloid in cases of nonunion of the navicular (Fig 289) particularly in those cases not suitable for grafting because of traumatic changes in the wrist joint. The Fracture Clinic at the Massachusetts General Hospital has had no experience with this form of treatment but has on occasion, excised the radial styloid when exposure of the fracture site of the navicular

was particularly difficult to accomplish

Steele advocated exposing the carpus on the dorsum and with osteotomes or a specially devised reamer cutting a circular piece including portions of the navicular capitate and lunate and rotating the section through an arc of 90 degrees thus serving to promote union between the three bones He immobilized his patients for only 3 weeks Of the 36 cases reported bone union had occurred in the 32 that were followed up

DRILLING —Another method of treatment of the ununited navicular bone has been that of drilling but as the years have passed, drilling has been largely abandoned as a treatment in favor of some form of graft.

AUTOGENOUS BONE GRAFT —The most satisfactory method of treating nonunion of the navicular bone is that of the autogenous tibial bone graft The first advocate of this procedure was Adams who in 1928 demonstrated a case in which bone union had been established by introducing a slot graft from the radius into the navicular bone. Murray inserted the graft through a drill hole from the tubercle through the distal fragment into the proximal portion Others have also advocated this method In considering the reasons for frequent nonunion of the navicular bone one must think in terms of blood supply and of the free motion through which the navicular bone normally travels as compared with the other carpal bones Therefore the combination of drilling and introducing a bone peg offers the best chance of re-establishing blood supply and at the same time securing fixation of the fragments In initial cases at the Massachusetts General Hospital the graft was placed in a slot on the dorsum of the navicular bone across the fracture line. The objections to the slot graft are that it is necessary to expose too much of the dorsum of the bone and to interfere with the blood supply to this region that too much bone is sacrificed from the navicular bone and that the method of fixation with the slot graft is not so secure as that with the dowel graft.

Technique of Bone Graft of the Navicular —A pneumatic tourniquet is placed around the arm After the usual preparation and draping of the forearm and hand a sterile Esmarch bandage is applied to the extremity The pneumatic tourniquet is then inflated to 275 or 300 mm Hg pressure and the Esmarch bandage is removed A curving incision with convexity toward

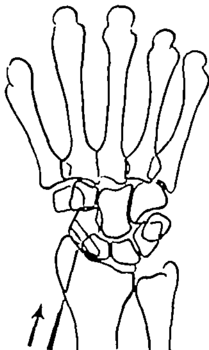


Fig 289 —Barnard s operation resection of radial styloid

the volar surface is made over the radial aspect of the wrist (Fig 290) The superficial branch of the radial nerve is identified lying on the sheath of the abductor pollicis longus and extensor pollicis brevis The capsule of the wrist is opened to the dorsum of these tendons and the nerve and tendons are retracted toward the palm If there is difficulty in exposing the distal fragment of the navicular the tendons can be retracted toward the dorsum The distal fragment is then identified A spatula is introduced between the navicular and the radius (Fig 291) and the fracture line is viewed With the spatula in place a small ⅛ inch drill hole is begun well toward the tubercle of the bone and is carried across the fracture line into the proximal fragment With

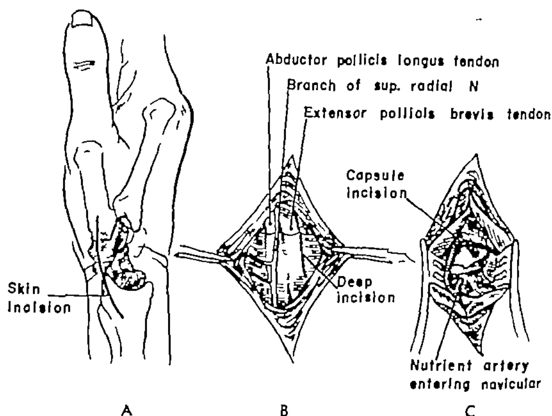


Fig 290 —Radial approach to navicular A, curved radial skin incision B exposure of tendons and sensory nerve C exposure of navicular bone

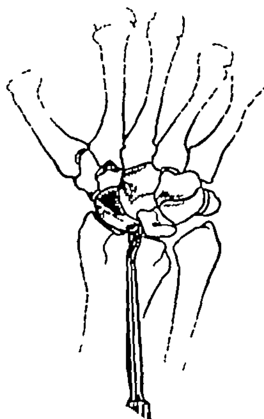


Fig 291 —Spatula holding navicular



Fig 292.—Nonunion of navicular 1 year after fracture Top oblique and anteroposterior views showing fracture in "waist" of bone with increased density of proximal fragment. Bottom 6 months after graft healing of fracture and incorporation of tibial bone graft

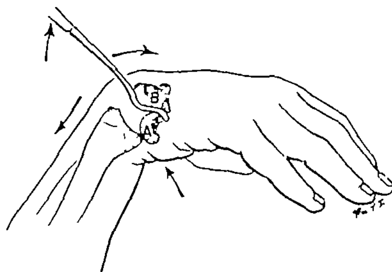


Fig 296 —Open reduction of lunate through dorsal incision using Davis skid. *A* lunate. *B*, capitate.

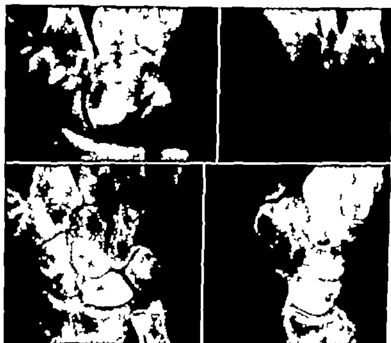


Fig 297 —Kienböck s disease following dislocation of lunate Top anteroposterior and lateral views showing the dislocation which was promptly reduced by manipulation Bottom same views 2 years later showing aseptic necrosis of lunate (Although this illustration is far from perfect it is reproduced because of the unique character of the case) (From Cave, E. F Kienböck s disease of the lunate J Bone & Joint Surg 21:858 1939)

back into place As traction is maintained the wrist is brought down into moderate palmar flexion Before any splinting is applied portable x ray films are taken and if reduction has been accomplished anterior and posterior plaster slabs are applied and held with a supporting bandage for 2 weeks

Treatment of Old Dislocations —If treatment has been delayed for longer than a few days manipulation may be unsuccessful in which case open replacement or possibly excision of the bone is indicated

If reasonable attempts at manipulation have failed the surgeon should proceed at once with an open operation. It is best to use a pneumatic tourniquet on the arm. If replacement of the bone is contemplated

a dorsal incision should be used in order to clear the space formerly occupied by the lunate (Fig 295) The skilled surgeon may be able to accomplish this operation through a transverse incision but if doubt exists as to the possible exposure a longitudinal approach should be used Occasionally incisions on both the dorsal and volar surfaces are necessary

If the surgeon believes that replacement of the bone is impossible because of scar tissue he may elect to excise the bone This



Fig. 298 —Kienböck s disease of the lunate (lateral and anteroposterior views) Note compression of lunate bone

is best accomplished by means of a transverse volar incision through a crease in the wrist The structures encountered are the transverse carpal ligament, under which lie the palmaris longus tendon and the median nerve and the flexor tendons These are retracted the joint capsule is opened and the displaced lunate is easily excised by dividing its remaining ligamentous attachments

LATE EFFECTS OF LUNATE DISLOCATION —If the lunate can be carefully replaced (Fig 296) it practically always survives despite the severe ligament laceration and partial interruption of blood supply associated with the injury Aseptic necrosis (Fig 297) of the bone or traumatic arthritis or both are possible late complications to be anticipated If either does occur excision of the lunate or possibly wrist fusion may have to be done

KIENBÖCK S DISEASE OF THE LUNATE

The term "Kienböck s disease" indicates a condition in which the lunate undergoes a slow progressive but incomplete degeneration with absorption of necrotic bone lamellae followed by fibrous-tissue replacement (Fig 298) The condition is not common Less than 100 cases have been recorded in the literature It is probable however that often the diagnosis is not made because the symptoms are frequently not severe and unless roentgenograms are taken the disease is not recognized

ETIOLOGY —Severe trauma is not necessary to produce necrosis of the lunate In 3 out of 9 cases at the Massachusetts General Hospital there was a history of a direct blow resulting in immediate acute disability and in 2 other cases in this series there was no known injury In all 9 cases how

ever partial necrosis of the lunate resulted The nature of the trauma may be a crush ing force applied to the bone resulting in a fracture of the bony contour or simply a contusion of the cartilaginous surfaces Or there may be a subluxation of the bone which reduces spontaneously but results in tearing of the dorsal ligament and subsequent interruption of the blood supply fol lowed by aseptic necrosis of the bone In a series of 19 cases of dislocation of the lu nate there was only 1 case in which Kien böck s disease subsequently developed. McBride reported 8 cases of old palmar dislocation of this bone and Kienböck s disease did not develop in any In 1 of his cases the dislocation had been present for 3 years.

PATHOLOGY —In 1 case at the Massa chusetts General Hospital the report on the microscopic sections was as follows

Much of the articular surface is essentially negative although patchy degeneration is evident [Fig 299] Immediately subjacent to the cartilage however along one entire edge of the bone penetrating its substance for about one half of its diameter there is an extensive necrotic process. This varies considerably in its appearance There are foci with complete necrosis consisting entirely of amorphous eosinophilic substance with relatively little exudative reaction The undersurface of the articular cartilage shows discrete, shaggy areas of chondrolysis Elsewhere in the osseous substance there are spicules of nonvital bone and an occasional focus of apparently new bone formation. Save for the region of complete necrosis the involved marrow substance exhibits dense fibrosis associated with a variable degree of lymphocytic and phagocytic infiltration Several groups of foreign-body giant cells are observed

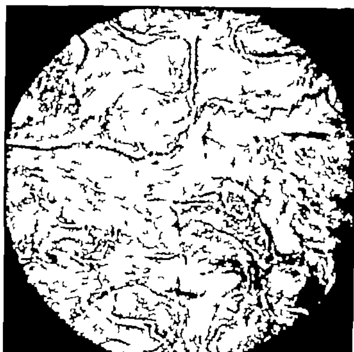


Fig 299 —Pathological section from a patient with Kienböck s disease

ROENTGENOGRAPHICAL APPEARANCE. — The changes are usually more marked at the proximal portion of the bone In the anteroposterior view early cyst formation and irregularity of the radial surface may be seen with some localized areas poor in calcium and others showing a marked increase in calcium content. As the disease progresses the bone becomes more dense smaller and irregular in outline taking on the appearance of a sequestrum Usually it remains in this state—a dead bone In certain patients the destroyed portion of the bone becomes fragmented In the lateral roentgenogram the density of the bone is increased and the proximodistal diameter of the bone is lessened whereas the anteroposterior diameter is increased.

SYMPTOMS AND SIGNS —The onset of the disease is insidious Frequently there is no history of injury that the patient can recall Other patients remember that their symptoms began with a severe strain of the wrist while lifting a heavy object still others give a history of a direct blow on the wrist or a fall on the hand with the wrist in dorsiflexion Characteristically the disease occurs in young males who do heavy work There may be a slow but definite increase in pain moderate stiffness and thickening of the wrist joint All symptoms are made worse by use of the wrist and improve with its rest and support Sudden forced motions may bring on severe pain

On examination the wrist is found to be moderately swollen and thickened in the anteroposterior diameter Thickening is most marked over the dorsum of the wrist in the central portion Local tenderness is usually acute and sharply localized to the center of the dorsum of the wrist The amount of limitation of motion varies greatly in the individual case In the acute stage active motion in any direction may be painful and passive motion may be carried out only to a moderate degree Dorsiflexion and palmar flexion are the motions most likely to be restricted and in the cases seen at the Massachusetts General Hospital ulnar deviation was more limited than motion to the radial side Making a complete fist is often impossible

DIAGNOSIS — The diagnosis of Kienböck's disease depends primarily on the roentgenogram for the history and examination only arouse suspicions of the lesion. The changes from the normal are confined to the lunate The condition may conceivably be confused with tuberculosis Tuberculosis however does not remain confined to a single bone of the carpus with this disease there is probably more generalized atrophy of the bones of the hand and the wrist. In tuberculosis also there is usually more synovitis of the wrist joint and possibly evidence of tuberculosis elsewhere in the body

TREATMENT —If the diagnosis is made early and before the degenerative changes in the bone have become advanced conservative measures consisting of support from a plaster or leather wristlet may help to restore nutrition to the bone and to prevent advance of the process When the bone is permanently deformed however and has the appearance of an irregular sequestrum or when it has disintegrated the only logical form of treatment is excision This operation should be done with great care in order to avoid trauma to surrounding structures If the changes have remained confined to the lunate—that is if traumatic arthritis of the wrist joint has not developed—we may expect good recovery of the wrist joint function with little or no pain after the diseased lunate has been carefully removed

RETROLUNAR DISLOCATION OF THE CAPITATE WITH FRACTURE OR SUBLUXATION OF THE NAVICULAR

Dislocation of the capitate bone with fracture or subluxation of the navicular was third in frequency of occurrence in a series of 186 cases of carpal injuries treated at the Massachusetts General Hospital

MECHANISM —Retrolunar dislocation of the capitate sometimes referred to as "transcarpal dislocation " is produced by a blow which suddenly forces the hand into dorsiflexion The commonest type of injury is a fall on the outstretched hand The force may be transmitted through the third metacarpal or may be received directly by the distal portion of the capitate The dislocation of the capitate is always accompanied by a fracture of the navicular bone or rotation luxation of this bone Usually great force is required to bring about such an injury When the injury occurs the ligamentous structures between the lunate and the capitate are ruptured and the blood supply is interrupted The lunate retains its normal relationship to the radius or it may be tilted slightly toward the palmar surface (Fig 300) The capitate is displaced dorsally to the lunate bone At the same time because of the shortening of the distance between the radius and the second row of



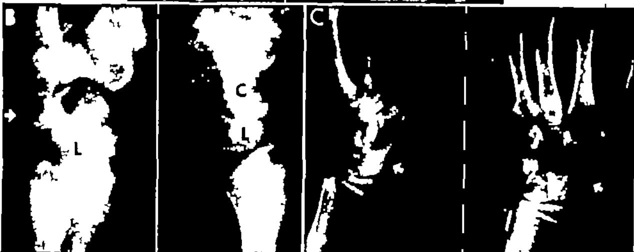


Fig 300 —Retrolunar dislocation of capitate with fracture of navicular Treated by closed reduction of capitate and by open reduction and graft fixation of navicular A, anteroposterior views of the injured and uninjured wrist. B lateral views of the injured and uninjured wrist (*L*, lunate *C* capitate) C end-result 1 year later bone union of navicular and excellent return of function.

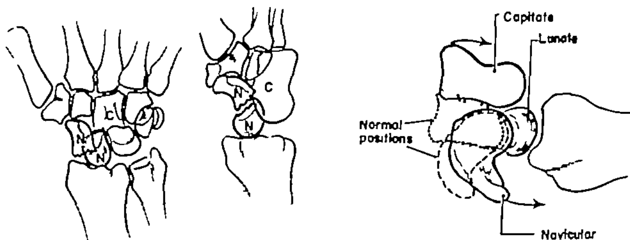


Fig 301 —Left retrolunar dislocation of capitate (*C*) with fracture of navicular (*N*) Right retrolunar dislocation of capitate with rotation of navicular Note that capitate is dorsal to lunate which maintains its normal relationship to radius

of the capitate there is a fracture of the navicular, the fracture may reduce spontaneously as the displaced capitate is restored to its normal position but if accurate reposition of the navicular fragment is not obtained, open reduction should be done and the fragments of the navicular should be realigned and held with a dowel graft (Fig. 300)

The graft operation must be performed within a few days otherwise it may be impossible to realign the navicular fragments satisfactorily even though the dislocation of the capitate may have been reduced If it is necessary to reduce the dislocation of the capitate by open operation as well as to graft the navicular a bayonet type of incision is used Postoperative fixation in plaster in this type of injury should be carried out until union of the navicular is complete

Treatment of Old Retrolunar Dislocation of the Capitate with or without Fracture of the Navicular Bone —The old dislocation probably cannot be satisfactorily treated by attempting to restore normal position of the carpal bones The surgeon must choose between (1) excision of the lunate and navicular bones and (2) wrist fusion. Excision of these two bones may result in improved motion and less pain in the wrist but will produce a weakened wrist, probably necessitating the use of external support for heavy work. Wrist fusion is the alternative to the excision operation. Fusion will produce strength and although motion in dorsiflexion and palmar flexion will be eliminated pronation and supination can be maintained since fusion is carried out only between the radius and the carpus.

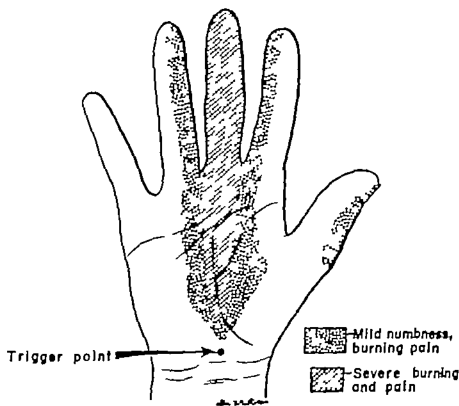


Fig 303 —Sensory changes with median-nerve injury

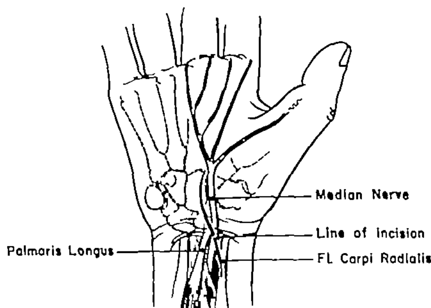
Traumatic Neuritis of the Median Nerve

A rare but very painful complication of wrist injuries is traumatic neuritis of the median nerve (Fig 303) The injury occurs at the volar aspect of the wrist as the nerve is compressed between the transverse

carpal ligament and the radius or carpus Usually the difficulty is manifested only by a transitory numbness in the hand and it may be short lived after injury and manipulation of the wrist This symptom requires no treatment because it usually disappears after days or weeks and does not recur

In the occasional case however symptoms of pain and burning in the palm may be extremely severe and may require immediate attention The onset may be gradual or immediate In one patient the pain came on overnight even though the wrist injury was of long standing An examination of the wrist and hand may reveal little except for moderate fullness of the hand owing to misuse On palpation directly over the course of the nerve under the level of the carpal ligament the pain and burning are aggravated Percussion in this area produces "shocklike" sensations into the palm (Tinel s sign) The x ray film may show evidence of old injury possibly with excess bone production on the volar aspect of the wrist

If pain and burning are severe and persistent division of the transverse carpal ligament gives complete and immediate relief (Fig 304) If there has been motor weakness of the muscles supplied by the median nerve recovery may be prolonged Cannon and Love of the Mayo Clinic reported their observations on 38 cases in 1946 They emphasized the necessity of distinguishing the lesion from conditions involving the cervical portion of the spinal



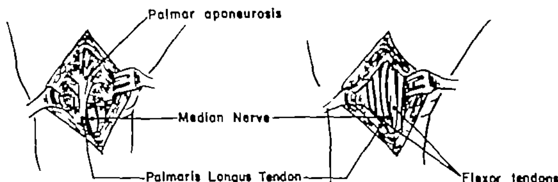


Fig 304 —Approach to median nerve

3 If a closed maneuver is unsuccessful and if the surgeon believes there is a reasonable chance to gain a stable reduction by open operation then surgery is justified

4 If open replacement and stability are not possible excision of fragments or an entire carpal bone may be justified but experience has shown that excision of the first carpal row does not give a strong painless wrist.

5 In the very severe injuries when replacement and stability are not possible and when trauma to cartilaginous surfaces is great fusion between the radius and the carpus may give the best result—that is a strong and painless wrist with dorsiflexion and palmar flexion eliminated but pronation and supination preserved

With a combination of injuries involving the carpal bones and other injuries to the upper extremity it is important to evaluate carefully by physical and x ray examination the shoulder the elbow and the wrist in order to rule out the possible associated fractures or dislocations

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23  Hand Injuries

THE IMPORTANCE OF hand injuries may be stressed by the fact that in the United States out of approximately two million disabling work injuries each year three quarters of them involve some permanent impairment of hand function * In the year 1950 the direct compensation that was paid for approximately 515 000 hand injuries amounted to $141 655 000 †

It is clear to anyone who sees a number of hand injuries that the initial medical care given these injuries bears a close relationship to the eventual result and that all too often the surgeon has been ignorant of or has ignored certain basic principles of hand surgery

During World War II the surgeon general of the United States Army found that of all types of injuries received by wounded men hand injuries had the poorest results It was ascertained that this was attributable primarily to the poor initial treatment that the injuries had received Following issuances of directives further education and as far as possible the eventual segregation of hand injuries in special centers the results became considerably improved The major causes of poor results in hand surgery are (1) unnecessary sacrifice of tissue (2) failure to convert an open wound into a closed one and (3) improper splinting To present an outline of the proper initial care of the hand injury is the purpose of this chapter

GENERAL PRINCIPLES

The following general principles should be observed

1 Accurate diagnosis should be made before embarking on any form of treatment

2. No treatment should be undertaken without proper equipment anesthesia and assistance

3 All wounds should be considered to be potentially infected and therefore to require some degree of debridement

4 All wounds should be closed by some means as soon as possible

DIAGNOSIS

Any severe hand injury is an open injury that is structures other than the skin and subcutaneous tissue have been damaged in some form and some manner It is of first importance to ascertain as far as

* *Work Industries in the United States during 1948* Bull No 975 U.S Department of Labor (Washington D C Government Printing Office 1950)

† National Safety Council quoted in Bunk B K and Wakefield A R *Surgery of Repair as Applied to Hand Injuries* (Edinburgh E. & S Livingston Ltd 1953)

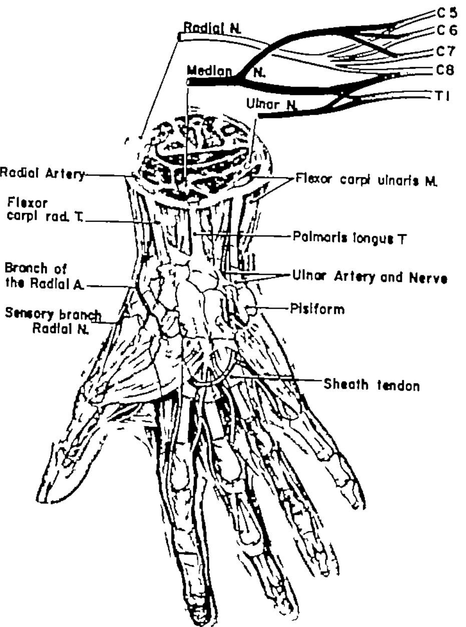


Fig 307 —Anatomical drawings of hand

possible exactly what has happened The type of accident—whether a laceration an amputation a crush or a burn—and the manner in which it occurred as well as the causing agent are of considerable im portance The length of time between the accident and the patient s being seen may occasion modifications in therapy For in stance if a tendon was divided 10–12 hours before the patient arrived at the hospital, repair would probably not be at tempted but the wound would be debrided and closed and the tendon repaired when the wound had healed

The less a wound is examined before the patient arrives in the operating room the better Each exposure adds to the probabil ity of sepsis therefore as much as possible of the examination should be done without removing the original dressing The degree of damage to skin and subcutaneous tissue may be inferred from the history Injuries to bone may be demonstrated by x ray Injuries to nerves and tendons may often be discovered by examination of exposed uninjured fingers Diagnosis of nerve in jury should be easy since all three of the nerves that may be involved—the ulnar median and radial—have a sensory com ponent (the radial nerve is purely sensory in the hand) The presence of normal sen sation distal to the injury precludes the possibility of injury to at least the sensory component It is important to remember that sensation in the tip of the index finger is derived entirely from the median nerve and that sensation at the tip of the fifth finger is derived purely from the ulnar nerve Similarly sensation on the dorsum of the first web space between the thumb and the index finger is purely radial In other parts of the hand some sensory over lap may exist so that anesthesia may not be complete If the injury has occurred in the palm of the hand distal to the proximal palmar crease where the main nerve trunks break up into digital nerves it is necessary to examine the sides of each finger to ascertain exactly which digital nerves have been injured In testing for sensation it is important that the patient look away because if he is watching the anticipation of a needle prick may mislead both the examiner and the patient and anesthetic areas may be presumed to have sensation This is particularly applicable to children

Motor branches may have been severed Therefore adduction and abduction of the finger should be attempted to see whether the motor component of the ulnar nerve has been involved In performing this test the hand and fingers should be extended and should rest on a flat surface so that the flexor tendons will not duplicate the movements Similarly opposition of the thumb which invariably is performed through the median nerve should be at tempted Opposition is not merely the abil ity to touch the little finger to the thumb but involves raising the thumb at almost a right angle to the palm of the hand and then moving the thumb across to the fifth finger There is no motor function of the radial nerve in the hand

In a similar manner the diagnosis of tendon injuries is attempted Tests should be made of the ability to flex and extend each finger separately It is very possible that injuries to the sublimis tendons of the fingers may be missed since the intact profundus tendons may duplicate the func tion of both the sublimis and profundus tendons but inability to flex the distal interphalangeal joints of the fingers implies injury to the profundus tendons The entire procedure of accurate diagnosis may be done in a very short time but it is time exceedingly well spent

TREATMENT

No treatment of a hand injury should be undertaken without proper anesthesia equipment and personnel Any delay in time is far to be preferred to sloppy slapdash procedures If the injury is severe anesthesia should be general or by brachial block For minor cuts local infiltration may be adequate A tourniquet is usually not necessary in the immediate care of the hand injury but an adequate tourni quet should be available in case of need

An effective tourniquet is a blood pressure cuff This is inflated to between 280 and 300 mm of mercury and then both rubber tubes are clamped off securely The cuff should be placed in position after wrapping the upper arm with Ace bandage or sheet wadding and it should not be inflated until the arm has been held up in order to drain out all possible venous blood It should be released during the operation at intervals of 1 hour and also at other times to demonstrate the vascularity of structures

There should be a plentiful supply of instruments adapted to hand surgery—mosquito forceps small rake or hook retractors small sharp scissors etc The surgeon who undertakes the treatment of *hand injuries should preferably be one who* is trained and able to do good nerve and tendon repairs and certainly able to do skin grafting If possible he should be the one who will follow the patient throughout his course and do any secondary repairs that may be necessary He should have adequate assistance

It is axiomatic that a hand injury—as indeed any other type of open wound—should be considered potentially infected and therefore debridement must be carried out Debridement means eliminating from the wound any structures which have been deprived of blood supply It includes the removal of foreign bodies and adequate irrigation It is equally important that every millimeter of normal tissue which can be preserved must be preserved and so debridement must be done with meticulous technique It is during this time that the impressions gained by the preliminary examination are confirmed and the exact degree of injury to the various structures ascertained No reparative work should be done until debridement has been concluded Bleeding arteries which are found during this maneuver should be ligated preferably with fine absorbable suture material 5-0 catgut being customary Irrigation with plenty of normal saline solution is of great aid Not only should blood and small foreign bodies be removed but the tabs of fat and areolar tissue that float up demonstrating their lack of blood supply should also be removed

Whether the reparative work is done immediately following debridement or whether the injury is of such severity that no reparative work can be done at that time the aim of the surgeon should be to close the wound. In simple lacerations this is not difficult. If skin loss had been a part of the injury some form of grafting is almost certainly necessary and usually this is best carried out by a split-thickness graft The worst results of hand injuries are found where the wound has been left open to suppurate and granulate This inevitably produces a deep and thick scar which at a later date must be excised together with what would have been normal tissue If closure is not effected, reparative surgery is delayed by weeks and mobilization of the hand may be delayed by months. During World War II, because of the type of injury produced by high velocity missiles it was found important that wounds be secondarily closed. This concept almost never applies to the hand It is only in extremely rare hand injuries that immediate closure after proper debridement should not be done

Repair of Skin

The skin is the most important structure of the hand and every hand injury deals to some extent at least, with the problem of closing or replacing skin The skin over different parts of the hand has widely varying functions That on the tips of the fingers is the most important source of tactile sense This sense is markedly interfered with by scar tissue The skin over the palm of the hand is attached to the underlying palmar fascia by thousands of little fibrous bands which prevent it from tearing while rowing a boat or pulling on a rope The skin over the dorsum of the hand particularly over the various joints is loose and thin and allows for complete freedom of flexion and extension. In repairing or replacing skin loss in these

areas particular attention must be paid to the properties of the original skin if good hand function is to result Therefore in general on the palmar surface skin without subcutaneous tissue is preferable for replacement and again in general the thicker the skin the less it will retract and the better it will stand up under wear and tear Occasionally flaps may be shifted from an unimportant spot to a more im portant area or a full thickness graft may be used Seldom will a pedicle graft which has subcutaneous tissue be suitable except on finger tips Conversely on the dorsum of the hand because of the need of mobil ity of skin and in many cases the possi bility or need of doing secondary tendon repairs the pedicle graft is usually the first choice Occasionally the situation may warrant the application of a pedicle graft at the time of the original operation Usually however it is best to cover up the defect with a split thickness graft. When this has healed completely it may be ex cised and a pedicle graft used as a defini tive surface

The so-called "pinpoint grafts" are of little use in hand surgery because the gran ulating area between the grafts produces an excessive amount of scar which will impair future function In applying any type of graft to the hand it is well to re member that the margins of the graft will undergo some degree of constriction and that therefore the margins should be so placed that they will not cross a web space and they should be fashioned in a curve *rather than in a straight line*

Repair of Tendons

Whether to repair a divided tendon or not at the time of initial operation depends on the extent and type of injury It is clear that unless it is quite obvious that the wound will heal promptly tendon repair which implies suture material of some sort, should be deferred until the wound has healed completely *In a clean laceration* on the other hand tendons may be re paired with impunity and almost certainly they should be repaired at the time of ini tial treatment

The method of repair probably makes little difference whether fine silk or stain less steel pull-out wires (Fig 308) are used depends on the preference of the surgeon Excellent results may be achieved with both Tendon repair done proximal to the tendon sheaths of the fingers presents little difficulty and any well-done repair *should develop essentially normal func* tion However tendon repair within a ten don sheath is more complicated There is no additional room in the sheath to allow for the inevitable swelling and edema which follows tendon suture and the dan ger of the tendon becoming adherent to its sheath or to another tendon at the site of repair is very great. *If both sublimis and* profundus tendons are divided within a sheath it is standard practice to excise the sublimis tendon and depend entirely upon profundus tendon repair for future func tion The sublimis tendon should be ex cised very close to its point of insertion at the base of the middle phalanx, or adverse *symptoms or dysfunction will result* The profundus tendon will produce flexion of both the proximal and the distal inter phalangeal joints and if both the sub-limus and the profundus tendons are re paired, they will almost always stick to each other or to the tendon sheath and the procedure will fail. If the transection *of the profundus tendon is close to either* end of the sheath the small remaining portion within the sheath may be excised and the tendon pulled either up or down so that it may be sutured outside of the sheath In all other instances it is far bet ter to excise the sublimis tendon and to rely entirely on the profundus tendon for function

In rare instances when the tendons within the sheath have become consider *ably traumatized or when it is felt that a* simple tendon suture will inevitably fail a primary tendon graft may be done How ever in these circumstances it is almost always wiser to do the graft at a later date than as an initial procedure The best

source of tendon graft is one of the toe *extensors* these can be removed with impunity It is exceedingly important to remember that any tendon graft, by itself will almost certainly become adherent at some point along its course Therefore the graft should include *not only the tendon but also its surrounding* areolar tissue or sheath. To obtain such a graft a straight incision is made from the base of one of the middle toes proximally over an *extensor tendon* as far as considered necessary The skin is dissected laterally and medially a suitable tendon chosen and the areolar tissue carefully divided well to each side of the tendon. The tendon together with its entire sheath is then excised A tendon suture is made distally as well as proximally in any suitable manner The end of the sheath can be fashioned so as to cover the suture lines. In determining the length of graft to be used *for a flexor tendon the wrist should be* flexed and the finger flexed in the position of rest there should be apposition of the graft and proximal tendon without tension In *flexor tendon grafts* as well as in simple repair the affected tendon should be immobilized for 3 weeks Extensor tendon repairs or grafts should be kept at rest for 5–6 weeks

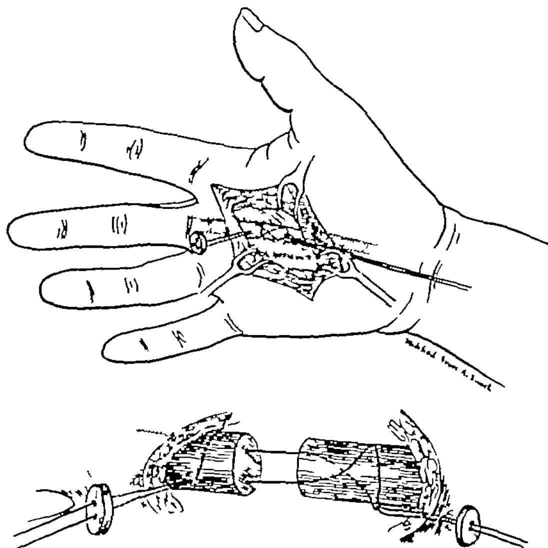


Fig 308 —"Pull-out" method of tendon suture (Modified from Bunnell)

Extensor tendon repairs unless there

has been loss of skin or of tendon can usually be done at the time of the initial procedure A very satisfactory method of repair is the *figure-of-eight stitch* involving tendon and skin (Fig 309) or more com plex types of tendon sutures may be em ployed The tendon must always be put at complete rest and in such a position that strain is not exerted at the suture line The extensor tendons are best immobilized by a splint that extends the wrist and involved metacarpophalangeal joint and allows flex ion of the interphalangeal joints

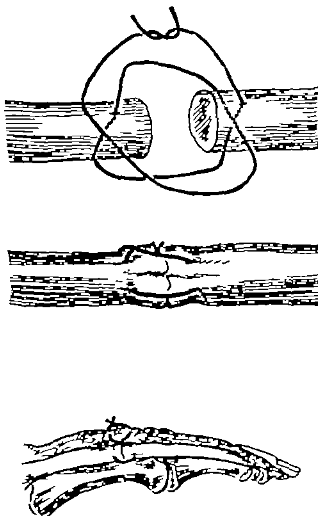


Fig 309 —Figure-of-eight tendon suture a rapid method. **Top** for extensor tendon repair **Bottom** for approximating both extensor tendon and skin

Amputation

Amputations particularly of finger tips are among the most common forms of hand injuries There are various ways of closing amputations and each method has a definite place The important factor to bear in mind is what the hand is to be used for An unskilled laborer is best served by being enabled to return to work at the earliest possible moment A stenographer or a pianist must have as long a finger as possible and an amputation stump that has normal tactile sense and no disagreeable sensitivity

Closure of an amputation stump by resecting enough bone so that flaps can be approximated without tension will allow return to work more quickly than will closure by a graft without removal of more phalanx The former will likely benefit the laborer the latter may be preferable for

the typist. As far as possible the method of closure and the probable result of such closure should be discussed with the pa tient. The type of work, as well as the pa tient s hobbies must be considered Unless *the decision is clear cut* finger length should always be preserved Any type of graft may be employed successfully Under ideal conditions a pedicle may be raised from the thenar or hypothenar areas and sutured to the finger tips and the resultant defect closed by swinging flaps or a split thickness graft. The use of a graft will require immobilization for 2–3 weeks but the result will be worth it if an optimal result is necessary

It should be borne in mind that irre spective of the type of closure steps should be taken to prevent the formation of sensory neuromas *The most effective means* of preventing this is to dissect out the in volved digital nerves exert traction on them and divide them so that they will retract back into unscarred tissue If all or essentially all of a nail has been ampu tated diligent excision of all nail bed and periosteum in the area should be at tempted so that bits of malformed nail do not grow *out of the amputation stump*

Fractures of Bones of the Hand

Injuries to the bones and joints of the hand are common and present an ex tremely variable picture The joints of the hand are the most important joints of the upper extremities and yet they are frequently neglected Fractures of the phalanges and dislocations of the interpha langeal joints are often considered trivial, although they are of great economic importance The so-called "minor" injury may cause months of disablement and inca pacity The aim of treatment of these injuries should be to restore the injured part to its normal function insofar as possible The hand has many and complicated motions the efficacy of which depends to a large extent *on a normal skeletal* framework. Thus it is especially important to return any distorted bony anatomy of the hand to normal

Great care must be taken in the treat ment of bone injuries of the hand and if certain basic principles are followed results can be expected to be satisfactory in most instances Far too frequently fractures *of the bones* of the hands are over

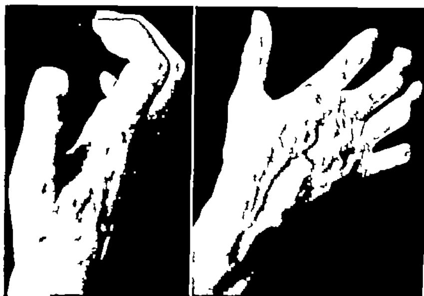


Fig 310 —Two views showing fixed flexion deformities of the interphalangeal joints the result of a tight plaster-of-paris casing used in immobilization of an undisplaced Colles fracture.

immobilized For most of these fractures 12–14 days of immobilization is adequate Care must be taken not to immobilize more than the injured part (Fig 310) If only one finger has been injured then only that finger should be immobilized The other fingers and thumb should be allowed free dom for active use and active motion When the injured part is finally mobilized no passive stretching of the joints should be allowed. Too frequently this causes further damage and more stiffening to the position Transverse fractures must be reduced and held and if they cannot be held by closed manipulation an open operation should be carried out without de lay An intramedullary nail can be used satisfactorily and will hold the fracture in good position It should not be left in for longer than 3 weeks since stiffness of the metacarpophalangeal joint may result Fractures of the heads of the metacarpals are best reduced and held in flexion It is almost never necessary to operate on them

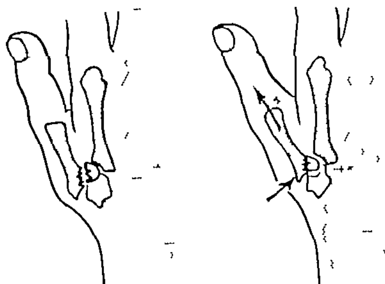


Fig. 311 —Left typical Bennett s fracture Right reduction of fracture by traction and pressure at base of the metacarpal

joints involved therefore gentle active use should be encouraged

Generally speaking, closed reduction of the fracture and maintenance of that reduction in whatever position holds it best will give the most satisfactory result Finger fractures should usually be immobilized in flexion The amount of flexion will be determined by the type of fracture and by the amount of flexion which will reduce and hold that fracture Immobiliza tion of the metacarpophalangeal joints in extension or hyperextension will almost inevitably result in permanent stiffness Fractures of the metacarpals of the second third fourth and fifth fingers present no great problem Spiral fractures may be im mobilized and usually they heal in good

Of special significance in metacarpal fractures is the so-called Bennett s fracture (Fig 311 *left*) a fracture at the base of the first metacarpal. This fracture usually ex tends into the metacarpocarpal joint. It is caused by a force applied to the tip of the thumb producing a shearing force at the metacarpocarpal joint. The shaft of the metacarpal is sheared off so that a small triangular fragment of bone remains on the inner side of the joint. This small frag ment usually remains in normal position whereas the shaft of the metacarpal dis locates proximally The injury thus con sists of a fracture through the base of the metacarpal and a dislocation of the meta carpal shaft To reduce this fracture-dislo cation traction should be applied in the

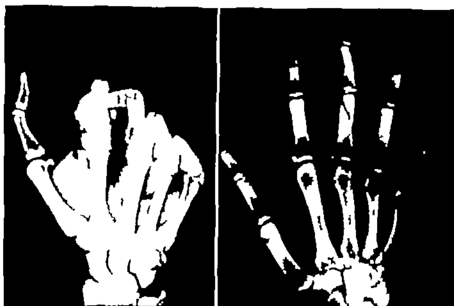


Fig. 312.—Left torsion fracture of distal portion of proximal phalanx midfinger resulting in rotation of distal portion of finger Fracture was by mistake treated with the finger in extension resulting in permanent rotation deformity (right) Proper treatment would have been gentle traction followed by flexion of all of the fingers toward the thenar eminence and maintenance of this position for 2 or 3 weeks

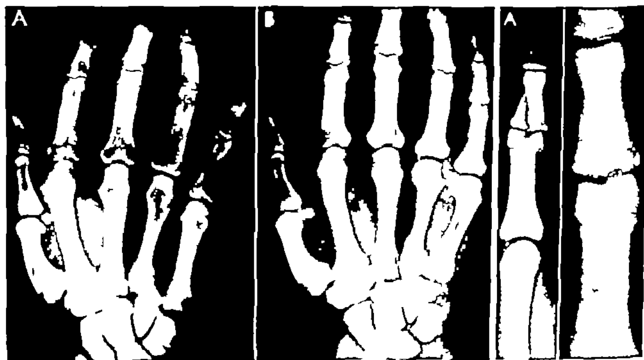


Fig 313 (left) —A, dislocation of base of fifth metacarpal secondary to a blow from boxing. B reduction of dislocation brought about by traction and maintained by 10 days support from a bandage

Fig 314 (right) —Bursting fracture due to a blow from falling stones A, x ray appearance directly after injury B result after 3 weeks of skeletal traction with a pin through the distal phalanx. There was marked soft-tissue scarring but the skin was not broken

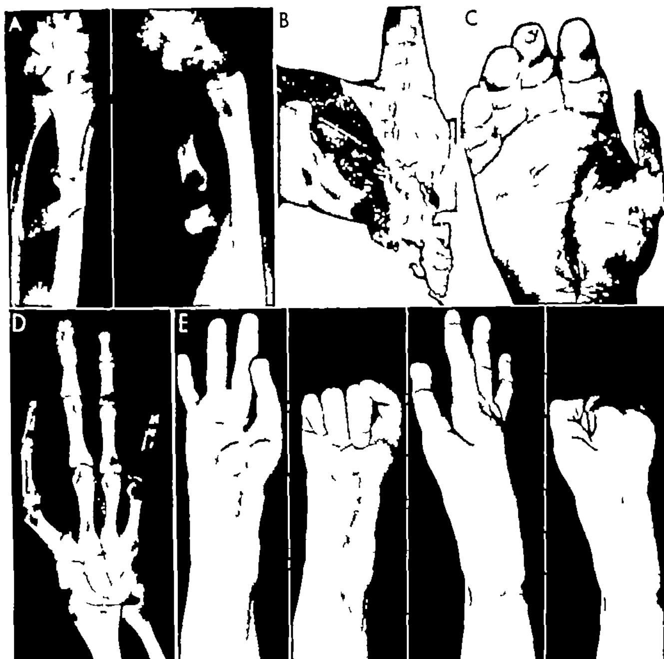


Fig 315 —A, subcutaneous dislocation of phalanges of thumb along with first metacarpal. The bones were displaced under the skin over the volar aspect of the wrist when the hand was crushed in a pressing machine B appearance of hand after the phalanges had been removed from the dislocated position skin of thumb intact. C gangrene of thumb 3 weeks after injury Although open reduction of the bones had been accomplished a few hours after injury circulation to the soft parts did not survive and amputation of the thumb at the base of the first metacarpal was necessary D x ray view and E, appearance of hand showing end result after amputation of thumb and transposition of forefinger to position of thumb

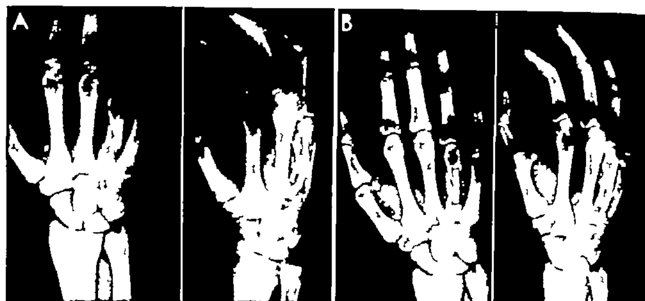


Fig 316 —A, two views showing nonunion of fourth metacarpal shaft of 6 months duration. B similar views showing postoperative iliac grafts with plate and screw fixation

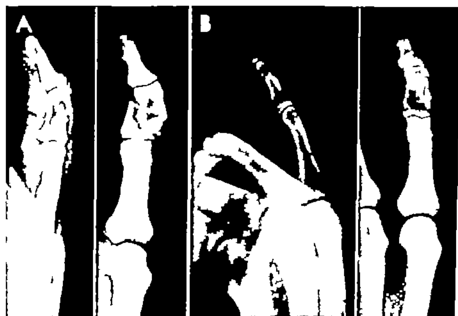


Fig 317 —A, anteroposterior and lateral views showing open fracture of midphalanx of fifth finger secondary to a severe blow B same views showing result after 2 weeks skeletal traction applied through the distal phalanx.

long axis of the digit and pressure applied over the base of the metacarpal (Fig 311 *right*) Maintenance of this position must be carried out for 3–4 weeks and this can be done by skeletal traction with a small Kirschner wire inserted through the meta carpal neck or the proximal phalanx. Many other forms of treatment have been ad vised varying from no treatment with early active use to routine operative reduc tion with screw fixation The method de scribed above has proved very satisfactory at the Massachusetts General Hospital

Fractures of the phalanges occur most frequently in the proximal phalanx (Fig 312) A fracture at this site can best be treated by flexion of the metacarpopha langeal joint with flexion of the proximal

and distal interphalangeal joints If the phalanx is immobilized in this position for 10–12 days union will usually result

Transverse fractures in the phalanges where it is impossible to maintain reduc tion in any position can frequently be very satisfactorily treated by intramedul lary nailing

DISLOCATIONS

Most metacarpophalangeal joint dislocations can be reduced without difficulty (Fig 313) Occasionally a dislocation results in a buttonholing of the capsule and reduction must be carried out by an opera tive procedure Dislocations of the inter phalangeal joints are common and reduc tion can be easily accomplished by traction on the finger usually in the position of flexion These injuries should be immobilized for 7–10 days Thereafter active use should be encouraged but passive motion and stretching are contraindicated

OPEN INJURIES

In many hand injuries there are both bone and soft part injuries (Figs 314 315 and 317) It may often be necessary to carry out bone repair and accomplish bone union before definitive soft tissue reconstruction can be done

Open fractures of the bones of the hand require the same general care as do open fractures elsewhere in the body The treat ment of these injuries must be carried out in the operating room just as for severe injuries to the soft parts of the hand In fection in the hand can be a horribly crippling complication, and casual treatment of these open injuries is to be condemned

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24  Fractures of the Pelvis

ANATOMY

THE COMBINATION OF the two innominate bones and the sacrum forms the pelvic ring which serves as a support for the trunk either through the ischial tuberosities in sitting or through the acetabula in standing The pelvic ring also supports and protects the pelvic viscera The weight bearing function is accomplished largely by the upper segments of the sacrum and the thick bars of iliac bone extending from the sacroiliac joints into the acetabula forming a posterior arch which joins the spine to the lower extremities Both the bone masses and the ligaments of the sacroiliac joints are heavy and strong and ordinarily they can be broken or torn only by violent forces

The two obturator rings form an anterior arch that serves for visceral support and muscle attachments Being thinner bone masses the pubis and the ischium along with the iliac wings the lower sacrum and the coccyx are likely to fracture by lesser forces

Because of the encircling shape of the pelvis wide separation or displacement at one point in the ring requires distortion of the ring at another point Distortion may occur at any of the three pelvic joints—the symphysis pubis or the sacroiliac joints—by dislocation or tearing or at a second site of pelvic fracture Although the forces of injury determine to a large extent, the deformity of a severely fractured pelvis, the trunk muscles inserting into the upper ilium pull a segment that is broken out of the pelvic ring up and through the posterior arch tending to maintain proximal displacement Strong contractions by the sartorius the rectus femoris or the hamstring muscles may pull off their respective attachments in the anterior superior spine of the ilium the inferior spine or the ischial tuberosity

Soft tissue structures contained in or passing through the pelvis particularly the distal genitourinary tract, are frequently damaged in severe pelvic fractures and very uncommonly the major vessels and nerves are injured

MECHANISM OF INJURY AND SEX DISTRIBUTION

Injuries involving those portions of the pelvis that have been fractured by less than violent forces—the obturator rings the sacrum and the coccyx—most commonly result from falls and more often affect women The severe fractures with displacement through the posterior arch formerly were incurred almost always in industrial accidents by men In recent years automobile accidents are a more



Fig. 318 —A, extreme widening of symphysis with tear of right sacroiliac joint and external rotation of right hemipelvis the result of an automobile crash. Both the bladder and urethra were torn Because of the massive damage to soft-tissue structures reduction of the dislocation could be achieved easily but owing to circumstances related to the other injuries early mobilization was preferred to holding the joints reduced sufficiently long for healing B reduction of displacement by manual traction and compression of pelvis from side to side followed by support from a pelvic sling for 6 weeks when walking was permitted with crutches and with the support of a sacroiliac belt At the end of 1 year patient was doing heavy work without symptoms. C end-result 5 years later Normal gait and no symptoms

common cause of these severe fractures and men and women are injured with equal frequency

Strong forces applied in the anteroposterior plane ordinarily stretch out the circumference of the pelvic ring by opening it anteriorly (Fig 318) this is typical of crush injury in which one or both of the innominate bones are rolled backward and out from a hingelike base at or near the sacroiliac joints Forces exerted from a lateral direction tend to diminish the ring circumference with collapse of the anterior arch and a rolling inward and forward of the large iliac mass of the hemipelvis (Fig 319) Such a deformity occurs when a person is struck from the side or when riding in a crashing vehicle he is thrown heavily sidewise against its wall. A combination of external rotation of one hemipelvis and internal rotation of the other (Fig 320) may occur producing rotation of the whole pelvis on the sacrum and spine

With wide displacement of a hemipelvis inward or outward i.e by rotation in a coronal plane some rotation ordinarily occurs in the sagittal plane as well, usually with tipping of the anterior obturator portion forward and of the top of the ilium backward

A severely displaced vertical fracture of one large portion of the pelvic ring often occurs with rotation (Fig 321) Such an injury is typically caused by the heavy wheel of a car or truck running over the side of the patient s pelvis after the patient has been knocked down by the vehicle.



Fig. 319 —**Left** inward collapse of pelvis by tear of left sacroiliac joint and inward dislocation of fractured left obturator ring which occurred when patient was thrown from a horse, which fell onto her left side This deformity is less common than an anterior opening of the pelvis **Right** after 48 hours with 25 pounds of traction applied through a Kirschner wire in distal left femur Crutch walking was begun 1 month after injury At 1 year normal function and no symptoms

TREATMENT

Isolated Fractures of the Pelvis

Isolated fractures of the obturator rings, the lower sacrum (Fig 322) the coccyx and the iliac wings (Fig. 323) ordinarily are only slightly displaced and will heal readily without impairment of function. After rest in bed for several days to a few weeks patients usually are comfortable enough to begin walking with crutches and early mobilization is desirable especially in elderly persons Discomfort in bed







Fig 320 —A, counterclockwise rotation of the pelvis on the spine in a 9-year-old boy as a result of fractures through the posterior right ilium and both obturator rings with dislocation of both sacroiliac joints The right ilium is rotated inward the left outward shifting the symphysis well to the left of the sacrum. The boy was struck from the right by a car B 48 hours after injury deformity reduced by recumbency and traction on the fractured right leg After 3 weeks a plaster spica was applied and the child was discharged to care at home C at 1 year pelvic contour mildly distorted but no defects of joint motions and no symptoms



Fig 321 —A, pelvic fracture in a girl aged 17 who was thrown from a colliding car into a roadway landing on her right side The right iliac fragment is driven only slightly upward the discrepancy between the inferior edges of the posterior right ilium and the sacrum is largely due to rotation of the iliac fragment in the sagittal plane Both hemipelves are rotated counter clockwise on the spine—the left by tearing of the left sacroiliac joint and the right by fracture through the posterior ilium The symphysis is rotated to the left. Fifteen pounds of traction was applied to the right leg through a threaded Kirschner wire transfusion of 1 liter of blood was given and within 24 hours of the injury her general physiological status became stable. There were no other serious injuries B some reduction of deformity by manipulation (under anesthesia) 36 hours after injury The manipulation included adduction of the legs over a bol ster placed between the thighs in an effort to realign the acetabular fragments The patient was returned to bed with 8 pounds of traction on the right leg. C after 6 days in traction consider able further change noted Clockwise rotation to realign the symphysis and spine and improve-ment in the position of the iliac fragments occurred with some overcorrection

may be reduced by the use of a pelvic binder or belt For patients with obturator ring fractures a pillow placed between the thighs makes turning less painful For those with such an injury as an iliac wing fracture which might be expected to en tail the development of ileus troublesome vomiting may be avoided by giving only parenteral fluids for a few days

A cloth pelvic support of the sort cus-tomarily called a "sacroiliac belt" will make resumption of activity less uncom-fortable and should be worn until symp-toms subside (Fig. 324) Lower back exer cises are prescribed during the period of convalescence

Often fractures of the sacrum and of the coccyx are difficult to demonstrate by

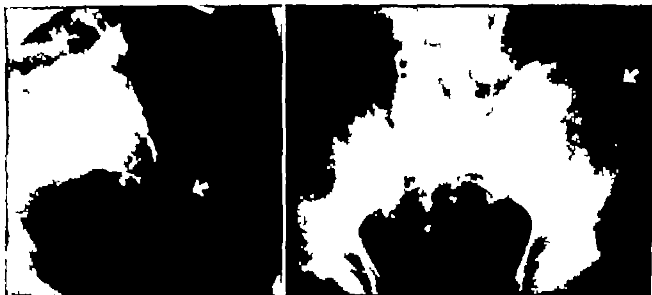


Fig 322 (left) —Fracture of lower sacrum (*arrow*) incurred when patient fell striking the edge of a step Previous standard x ray examination of the pelvis had not disclosed the injury and the patient s complaints had been untreated Bed rest and sacroiliac corset sufficiently relieved the severe pain to allow the patient to begin walking after 1 week.

Fig 323 (right) —Comminuted fractures (*arrow*) of the left iliac wing which resulted when the patient was struck from the left by an automobile The left kidney was contused At rest in bed and wearing a pelvic binder the patient was soon comfortable At 2 weeks he began walking, wearing a sacroiliac belt

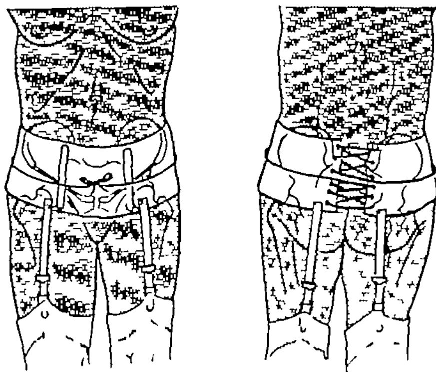


Fig 324 —A simple sacroiliac belt Thin pads on the inner surface of the belt fit just lateral to posterior iliac crests The top of the belt should rest just at the midpoint of the iliac crests held there by garters (in women) or by perineal straps (in men when necessary) For women the top circumference of the belt is 4 inches less than the bottom for men only 2 inches less

of acetabular fracture sufficient hip capsule and muscle attachment to this major fragment remain to allow the use of the lower extremity for positioning the fragment direct control by push or pull on the anterior portion of the iliac wing is possible It should be remembered that this large fragment is displaced by bending or rotating it in or out anteriorly on a hinged base posteriorly and not displaced as a whole in a lateral direction.

When extreme displacements exist extensive ligament and fascial tearing has occurred A completely ruptured and dislocated joint does not require great force for reduction and usually fragments of a severely dislocated or fractured pelvis are not difficult to move Slight subluxation of a sacroiliac joint is more difficult to reduce than wide displacement

Muscle attachments around the pelvis are very broad with the points of insertion of the trunk muscles often fusing with the tips of the thigh muscles While the large trunk muscles attaching to the pelvis and the psoas muscle do tend to maintain proximal displacement of a hemipelvis or the major iliac fragment, displacement primarily because of muscle pull is not a regular problem in the treatment of these injuries

Because violent forces are required to produce pelvic injuries with displacement through the posterior arch additional serious injuries away from the pelvis are common. The displacement of pelvic fragments often results in injury to the soft-tissue structure contained in and passing through the pelvis Loss of blood into the retroperitoneal spaces occurs regularly sometimes in massive quantity Prompt treatment of the total injury is necessary and blood transfusion is frequently required

During the period needed to assess damage to treat critically urgent injuries and to bring the patient to physiological stability one or both legs depending on the configuration of pelvic deformity should be suspended and traction applied An inverted half ring Thomas splint with a Pearson attachment is a good suspension apparatus With it a threaded Kirschner wire through the lower femur with 15–20 pounds of traction is used, and the hips are moderately abducted and flexed and the legs maintained in neutral position

Management of this type will not upset the patient s sometimes precarious status Instead it will reduce discomfort and will not interfere with the treatment of any other possible injuries

Most of the severe deformities will be greatly improved or reduced completely by traction-suspension of the legs The effect of traction-suspension on a collapsed ring with inward rotation of the ilium on upward displacement in a vertical plane and on rotation in a sagittal plane may be easily appreciated. This form of treatment is also effective in reducing the type of deformity which occurs when a proximal femur falls backward to a position behind the ilium at the time the pelvis is opened anteriorly by outward rotation of the ilium. By bringing the proximal femur forward from this position suspension traction acts in a way like a pelvic sling (Fig. 327) which exerts its maximal force on the most prominent portions of the pelvic area, the greater trochanters

Occasionally a pelvic sling assists in reducing or holding a widely opened pelvis. However patients often find a sling uncomfortable complaining of pressure over the trochanters also slings often make nursing care and treatment of genitourinary and other abdominal injuries awkward. A sling should not be used when an injured pelvis is collapsed inward or when the femoral head has been driven into or through the acetabulum

While the effect of continuous traction-suspension is accomplished gradually great improvement is usually apparent in 24–48 hours In effect the patient s movements act as limited manipulations during this period but as with other fractures treated by traction major pelvic fragments may be more deliberately positioned manually Because the fragments are rarely impacted and because with severe deformity there is severe relaxation of

soft tissues the fragments ordinarily are moved easily and anesthesia may not be required

At times early manipulation under anesthesia is desirable and then it should be done as soon as the patient s general status allows it This applies particularly to injuries in which displaced fragments jeopardize circulation to the lower extremity or prevent adequate treatment of visceral damage It also applies to subluxation of the sacroiliac joints without severe ligament damage since this sort of injury may require extreme traction force for reduction without anesthesia.

Because displacement of the ilium is usually posterior upon the sacrum manipulative reduction of this injury is done by laying the patient on his sound side with the thigh of the dislocated side rolled forward. Pressure applied directly over the ilium in an anterior direction will reduce the subluxation

After manipulation the patient is returned to traction-suspension and often a position of incompletely reduced fractures

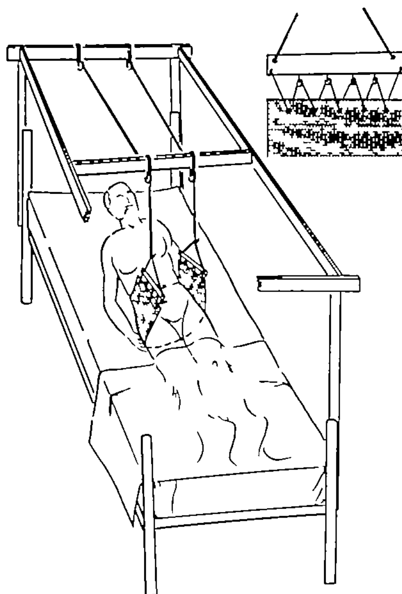


Fig. 327 —A pelvic sling The force of lateral compression of the pelvis by the sling can be increased to some extent by suspending the sling s free ends in close approximation The system of multiple pulleys allows the sling to fit the pelvic and hip contour closely

is improved during the several days following The reduced position is sustained with gradual reduction of traction weight for 4–6 weeks or longer when large fractures are involved. Injuries which are entirely joint dislocations may require a shorter period of 3–4 weeks if examination reveals sufficient stability to allow the patient to begin weight bearing with crutches. The pelvis is then supported by a sacroiliac belt and back exercises are begun

In children when the position of reduction has become sufficiently stable a plaster spica may be used to shorten the period of hospitalization In adults traction is ordinarily continued until mobilization can be begun

While the method of reduction in lateral recumbency with the use of a plaster spica for immobilization is logical for patients who have fractures that are opened out anteriorly its use is often precluded by the presence of other injuries and traction suspension is preferred

Well leg traction and turnbuckle casts of the legs which aim to accomplish lateral distraction or coaptation of the hip joints as a force of reduction do not take into account the hinged like displacement of the major fragments They also have the objection of possible damage to skin nerves and blood vessels damage which may accompany any strong force continuously applied

Open treatment of pelvic fractures is rarely indicated and then only when an irreducible bone fragment is involved in an injury to important soft parts While restoration of nearly normal pelvic contour ought to be achieved elaborate operations designed to fix iliac wing or obturator ring fragments usually are unnecessary and hazardous

Results of Treatment

When grossly normal pelvic contour is restored there is no appreciable impairment of function Moderate bone deformity and moderate distortion of the symphysis pubis usually will not cause symptoms. Persistent sacroiliac subluxation and sometimes the effects on the joint caused by the trauma of dislocation even though reduced may produce lasting backache, preventing the resumption of full activity Sacroiliac arthrodesis may be required for the relief of pain Fractures near or at the sacroiliac joint less often result in persistent pain

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25 

Fractures and Dislocations of the Hip

HISTORICAL

IN A REVIEW OF THE LITERATURE Peter Cordasco found that Ambroise Paré (1510–90) was the first person to recognize and make a written report on the recognition of a fracture of the hip Freely translated Paré s report reads

> I had observed the hurt thigh to be shorter than the whole with the outward prominence of the ischium. I persuaded myself it was a dislocation of the hip I then extended the thigh bone and forced as I thought, the head into its cavity The equalities of both legs which follow the point of this extension increased my persuasion that it was a dislocation The next day I visited her and found her in great pain, her hurt leg shorter and her foot rested inwards [This position may represent over reduction with the distal neck being dislocated behind the head fragment.] Then I loosened all her ligatures and perceived such a prominence as I did formerly When I tried again to force the head of the bone as I did before I heard a little crackling and also I considered there was no cavity or depression in the joint and by this sign I persuaded myself that the bone was broken at the hip and not dislocated. I therefore set the bone and joint and the fragments together laid splints thereon with compresses made ligations with a rowler having two heads wrapped about the joint and the body crosswise and I defended her foote with a case that none of the clothes might press it. I fastened a rope to a post and so let it come down into the midst of the bed and tied therein many knots for the better taking hold and lifting up herself

From this description of a fractured hip and his care of the patient, Paré has given us the cradle to keep the bedclothes off the feet and the overhead rope for the patient to help himself about in bed (Fig 329)

The ideas of how to treat fractures of the neck of the femur have been about as varied as the number of surgeons who have written on this subject.

Hildanus (1537–1619) first applied the principle of extension and counterextension through a system of multiple pulleys This same principle had been applied by Hippocrates Our present knowledge is improved by a clearer understanding of the details of the anatomy of the hip and leg and the pathological findings regarding fractures of the hip

Pott (1713–88) utilized the semiflexed position of the hip and knee to neutralize the muscles of flexion and extension to a point of balance He also placed the patient on the affected side with the plane through the anterior iliac spine perpendicular to the horizon

The development of many complications led to the gradual abandonment of the many variations in the methods of management. Cooper (1768–1841) used the

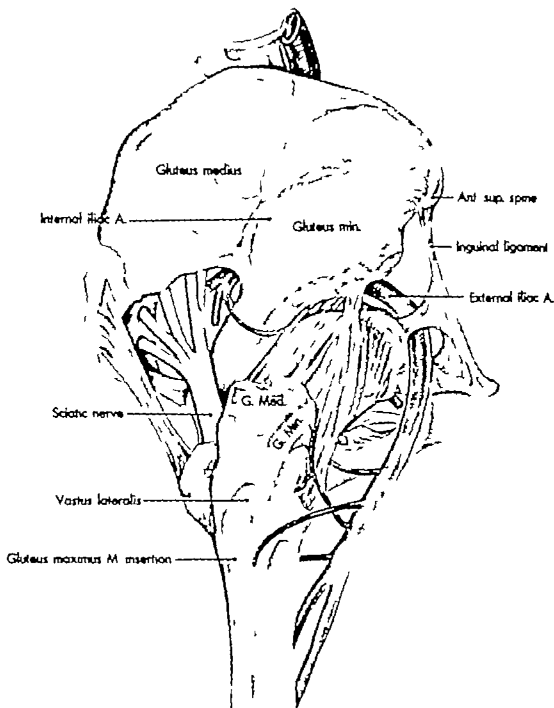


Fig 328 —Anatomy of the hip joint

double inclined plane or pillow under the knee He was also the first to classify hip fractures into "intracapsular" and "extracapsular" types And he brought out that the prognosis for union in the intracapsular type was very poor and in the extracapsular type very good

In 1861 Buck described the application of traction to the thigh by pulling through the knee Variations of this method are in use today—the wire traction through the tibia and Russell's traction with the addition of the knee sling All of the foregoing methods have left fragments of usefulness that are employed today

The use of a metal nail to hold together

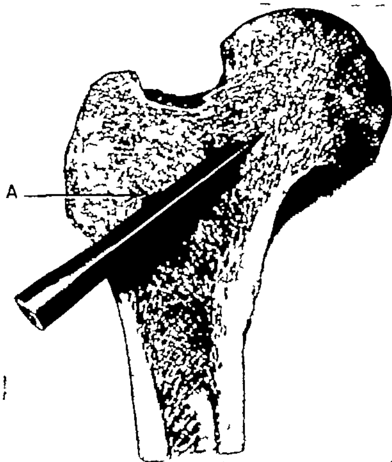


Fig 330 —The Smith-Petersen nail. The blades of the nail are thin where they enter the head of the bone and they are shaped like an osteotome so that they will compress bone as they advance Note that the trabecular pattern in the femoral head is dense and the stress lines easily visible A arrow points to space occupied by one blade of the nail this represents a lot of surface but only a small amount of space

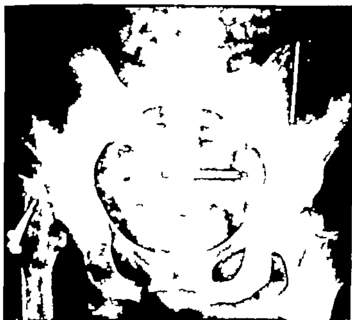


Fig 331 —Migration of wires Three wires were used to secure a fractured femoral neck. All broke and the proximal fragments of the wires migrated into the pelvis This hazard must always be kept in mind when wires are used.

ping on slick sidewalks and on waxed or wet floors and from tripping over scatter rugs and over electric wiring lead the list of causes precipitating these injuries Muscular effort can also fracture hips Some patients have related that they heard the hip break and then they fell This is particularly likely to happen in the elderly and the physically inactive patient with osteoporosis and/or malignant disease

Metastatic disease primary tumors and changes following radiation therapy may be *the underlying cause of fractures of the* neck of the femur A very minor force—even turning over in bed—may be all that is necessary to precipitate a fracture in these conditions

Bilateral fractures of the neck of the femur have been produced by shock therapy

Falls in which the patient lands on the greater trochanter can produce impacted fractures of the neck of the femur An impaction of this type is usually in a favorable position so far as prognosis for union is concerned and may need only supportive and guided management However such impactions can be in an unfavorable position in which case they will hold together for only a few days Careful physical examination and x ray studies are essential in deciding on the proper management of the individual case

Anatomical Deformity

The usual deformity of the leg in a patient with a fractured hip is one of adduction external rotation and shortening The greater trochanter is prominent posteriorly and is higher than on the normal side Various degrees of this deformity are found As a rule the patient will be unable to lift the leg

The physical findings may consist of only minor changes such as a small amount of shortening (by measurement ¼–½ inch) a few degrees of rotation deformity (as compared to the opposite hip) and or a mild prominence and upward displacement of the greater trochanter Any or all of these findings should lead the surgeon to suspect a fractured neck of the femur which has been impacted or one which has impaled the capsule and is impacted in a poor position Trying for crepitus is not indicated The surgeon should rely on proper and adequate x ray studies to confirm the diagnosis (Fig 332)

Variations from the classic deformity of a fractured hip may occur In a patient who has fallen directly on the greater trochanter the findings may reveal a slight increase in the length of the leg a slight *knock knee deformity* and a local hematoma over the greater trochanter The trochanter may be lower and less prominent, and the external rotation deformity may be absent With these findings it is almost certain that *there is a fracture of the neck* of the femur with impaction of the fragments in a valgus position Loss of internal rotation usually means impaction in external rotation Loss of external rotation may indicate impaction in internal rotation In most impacted fractures the patient can move the leg about relatively freely and he may have walked on it with minimal pain The only complaint may be soreness or stiffness following a fall.

An unusual deformity associated with femoral neck fractures may be internal rotation of the extremity This position may be due to displacement of the femoral neck behind the head of the femur or it may indicate a base-of neck fracture in which the fulcrum of rotation is at the capsule

Emergency Treatment

The splinting of a fracture is often the best medication. A minimal amount of opiate is all that should be used Splinting should be applied before the patient is moved

The use of a Thomas or Hodgen splint with traction through the foot and ankle is a good method in competent hands A simple method, and one that is just as effective is to apply *traction to the injured* leg in the line of deformity and then bandage the leg to the normal one using a pillow between the knees and ankles An

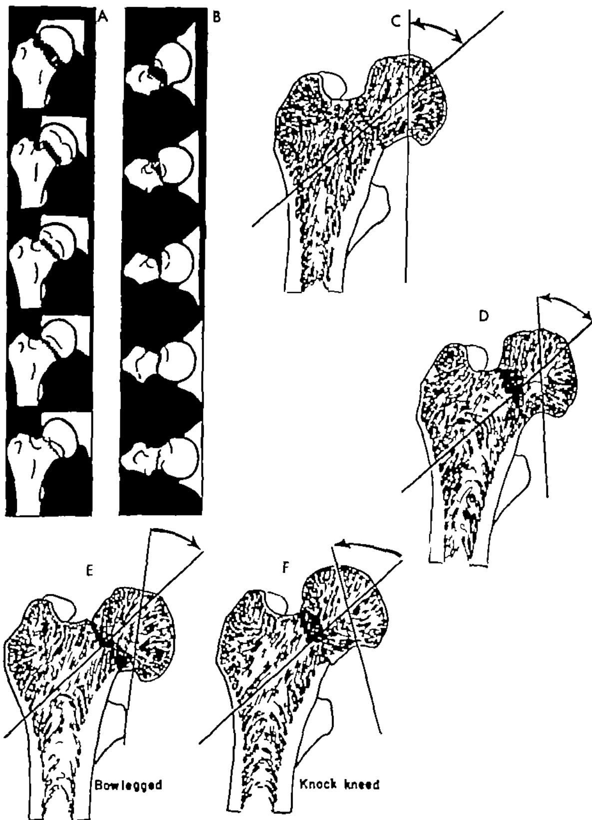


Fig 332.—Mechanism of displacement of fractured neck of femur A, progressive displacement of a fractured hip from below upward. B the lateral displacements It is noted here tha favorably impacted fractures will represent a stage in any fracture Widely displaced fracture probably go through a favorably impacted stage The fracture in C progresses to a favorable va gus position shown in D Greater force will increase the valgus position as in F which is ur favorable and not stable In this position of impaction the weight-bearing lines force the le into a knock knee A displacement into a varus position (E) produces a bowleg position.

* [Ed. note.—Some members of the Fracture Clinic of the Massachusetts General Hospital do not be

assistant should hold the ankles firmly together while the legs are bandaged from the ankle to above the knees While the ankles are being held firmly together traction is applied through the injured hip and countertraction to the uninjured one as in the so-called "well leg traction" After the bandaging another pillow is placed under both knees for comfort. With such pillow splinting transporting the patient can be most easily done by lifting him into a straight chair and carrying him in the chair in a semireclined position—i e using the chair as a litter Transferring the patient from the chair to a regular litter is easily accomplished by lifting the patient from the reclined chair to a stretcher keeping the patient s knees bent and resting them over a pillow

X RAY EXAMINATION

Two views—anteroposterior and lateral—will serve as a guide for planning the management of the fracture The lateral view can be taken by rolling the patient toward the injured side and then directing the x rays across the front of the normal thigh The quality of the x ray films should be such that the surgeon can easily study the trabecular pattern in the head and neck of the femur (Fig 333) With such detail visible in the films he can more accurately plan the manipulative reduction or changes necessary to secure more favorable positions A minimum of two views is necessary to understand and manage fractures

IMPACTED FRACTURES OF THE NECK OF THE FEMUR

There are two types of impactions of fractures of the neck of the femur one favorable and the other unfavorable for bone union (Figs 334–336)

Bone union will almost always follow impacted fractures of the neck of the femur if the head fragment is rotated in a slightly valgus position in the anteroposterior view The angle of the valgus position should not be greater than an angle in which the general trabecular pattern of the head fragment is less than perpendicular * A valgus position forming an angle greater than this may result in aseptic necrosis (Fig 337) This degree of impaction visible in the anteroposterior view will show an area of increased density along the fracture line which is wedge shaped the base of the wedge above In the lateral view the impaction that is favorable will also show a wedge-shaped area of increased density along the fracture line The base of this wedge is usually seen anteriorly although it may be seen posteriorly depending on the rotary element in the impaction. The cortex of the femoral neck opposite the base of the wedge must be in contact if the impaction is to be in a position favorable for bone union (Fig 338)

The impacted fractures which are in positions unfavorable for bone union are those in which the head fragment is in a varus position or in which the trabecular pattern is less than the normal angle of the neck The weight bearing force in these fractures is toward the horizontal. The internal and external rotatory elements of these impactions are relatively the same as in the valgus positions The varus position in itself is the dominant factor for a poor prognosis for bone union. This is true even for hip fractures nailed in a varus position.

Management of Impacted Fractures

The favorably impacted fracture of the neck of the femur in the valgus position

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lieve that an increased valgus position is necessarily a hazard since experience does not indicate that aseptic necrosis is caused by an increased valgus position. The varus position is of course highly undesirable because the shearing force is increased. Note Figure 347]

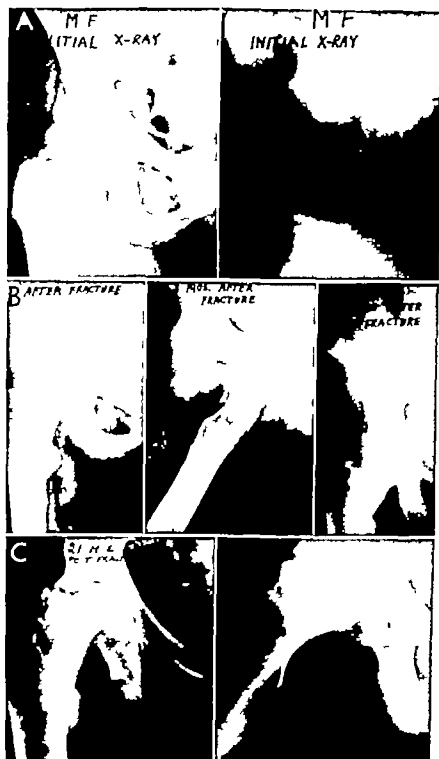
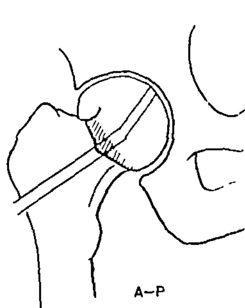
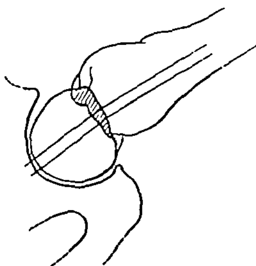
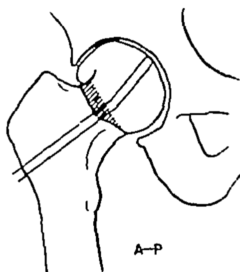


Fig 333 —Good quality of the x-ray films is important. A, hip fracture assumed to be favorably impacted, but opinion was based on these films of poor quality B 3 months after injury the patient continued to have pain Again the x ray films were of poor quality C, 21 months after injury the films revealed localized aseptic necrosis. Good detail in the early films may have revealed that this fracture was impacted into too great a valgus position







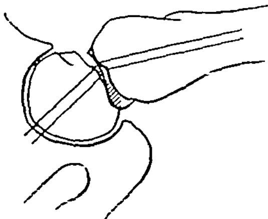


Fig 334 (top) —A favorably impacted fracture of the femoral neck—areas of increased density in both anteroposterior and lateral views The head is not rotated into too great a valgus position This fracture should not be tampered with

Fig 335 (bottom) —An unfavorably impacted fracture of the femoral neck—one area not in contact usually revealed in the lateral view This fracture should be reduced and held with internal fixation

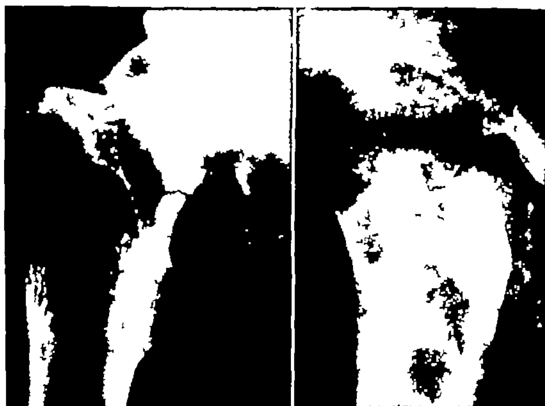


Fig 336 —Left anteroposterior view showing an area of increased density at fracture site upper portion of femoral neck. There was excellent range of motion and very little pain. Right, lateral view showing only one cortex intact The impaction was not safe and accordingly with a minimum of manipulation, the fracture was reduced and nailed.

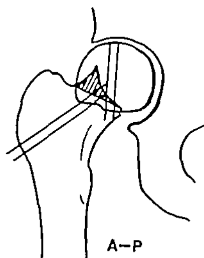


Fig 337 —A fracture of the femoral neck which is impacted into too great a valgus position and which will almost surely go on to some complication—either (1) an area of aseptic necrosis or (2) nonunion of the fracture

may need nothing more than symptomatic management. This should include bed rest with the injured leg suspended in a splint with a few pounds of traction just sufficient to keep the leg comfortably in the splint The time required in this splint and traction should be sufficient to allow for soft tissue healing A period of 4–6 weeks is usually sufficient During this period in bed the patient should have a definite set of general exercises including deep breathing and frequent changes in position from sitting up in bed to lying flat for films and by symptoms This time interval may be from 4 months to a year

There are surgeons who feel that it is a safer procedure to have some kind of internal fixation for the favorably impacted fractures they believe that this will prevent loss of position and will allow the patient earlier mobilization They advocate the use of long screw fixation 3-flanged nailing multiple screws or wires etc since they believe that internal fixation insures that the fracture will heal. This is probably true provided that the effort of



Fig 338 —Impacted fracture of femoral neck in position favorable for union and function Such a fracture should not be tampered with During 18 years of follow-up hip has functioned practically normally

a period of ½ hour at least three times a day During the lying-down periods he should carry out abdominal retraction gluteal and quadriceps setting anterior tibial pull, and toe-curling exercises Exercises in bed will make the time pass quickly and will prevent the general musculature from becoming flabby

After the initial period of from 4 to 6 weeks in bed the patient should be allowed up with weight bearing supported by crutches for from 4 to 6 months Full weight bearing may be allowed when the fracture has healed as evidenced by x ray

fixation does not displace the fracture Rarely however does the femoral neck fracture that is truly impacted in valgus fall apart

Is a Displaced Fracture of the Neck of the Femur an Emergency?

There is universal agreement that early splinting or the application of traction to a displaced fracture is good management. It also follows that early fixation of fractures in the position in which healing should take place is desirable These prin

ciples apply particularly to fractures of the neck of the femur Such fractures should be reduced and nailed as soon as possible Long delays in treatment for the convenience of the surgeon must not be accepted It must be realized however that the general condition of the patient should be carefully evaluated and if severe cardiac disease or diabetes is discovered these conditions must be rapidly controlled before surgery is carried out Early fixation of the fracture will reduce shock, the patient will be made more comfortable and the general condition will improve

ANESTHESIA.—Less shock is produced in an elderly patient if anesthesia is started when he is in the traction splint in bed During any transfer of the patient the surgeon or a responsible member of his team should manage the fractured leg in order to prevent undue trauma or further displacement During the induction of anesthesia the leg should be held and steady traction maintained in the line of deformity As the patient relaxes under the anesthesia, a slow correction of the deformity can be obtained by simple maintenance of traction and correction of the position of deformity Allowing a fracture to lie free on the table during the anesthesia permits additional damage and further deformity This small detail may make a major difference in the reduction and the eventual fate of the fracture

The anesthesia to be used for the reduction of fractures and dislocations of the hip remains the choice of the surgeon. With the many aids of modern anesthesia a combination of useful drugs is often best Thiopental sodium for induction and combinations of gas-oxygen and ether are used most commonly in the Fracture Clinic at the Massachusetts General Hospital Gas-oxygen with ether is probably safest. Where complete relaxation is necessary such as for reduction of a dislocation of the hip or for shortening in an intertrochanteric fracture the addition of curare or Anectine® is invaluable These aids should of course be administered by a well-trained anesthetist Spinal anesthesia has its place but when difficulties are encountered substitutes are often needed.

In the preoperative medication, heavy "snowed under" opiates should be avoided. Atropine and thiopental sodium seem to be most satisfactory

Principle of Reducing a Fractured Neck of the Femur

The problem of reducing a fractured femoral neck is the same as that for any other fracture—to return the two fractured surfaces to their anatomical continuity The management after reduction is to hold the fracture until adequate healing has taken place The methods of accomplishing reduction and fixation are numerous. The applications of some of the ideas regarding reduction, however may be useful in the problems immediately at hand. Although it is true that in the management of a particular case experience becomes more valuable than knowledge knowledge gives finesse to experience (Fig. 339)

A thorough understanding of the bony and muscular anatomy about the hip is a prerequisite to the reduction of a fractured neck of the femur (see Figs 385 and 386 pp 480 482) A certain amount of luck may occasionally result in a perfect reduction but that luck will be more constant if the operator understands what the bony anatomy is like There are more pitfalls to the reduction and to the maintenance of a reduction of a fractured neck of the femur than for any other bone

Two factors make the manipulation difficult (1) The distal fragment is the larger one (2) The proximal fragment is smaller and its hemispherical end lies in a slick socket and anatomically at an angle with the weight-bearing lines It is also easily capable of rotating through 180 degrees at the slightest touch because of its lack of muscular attachments after it has been fractured The easy way to reduce a fracture would generally be to put the smaller portion onto the larger but in the fractured neck of the femur the larger piece must be handled and placed on the

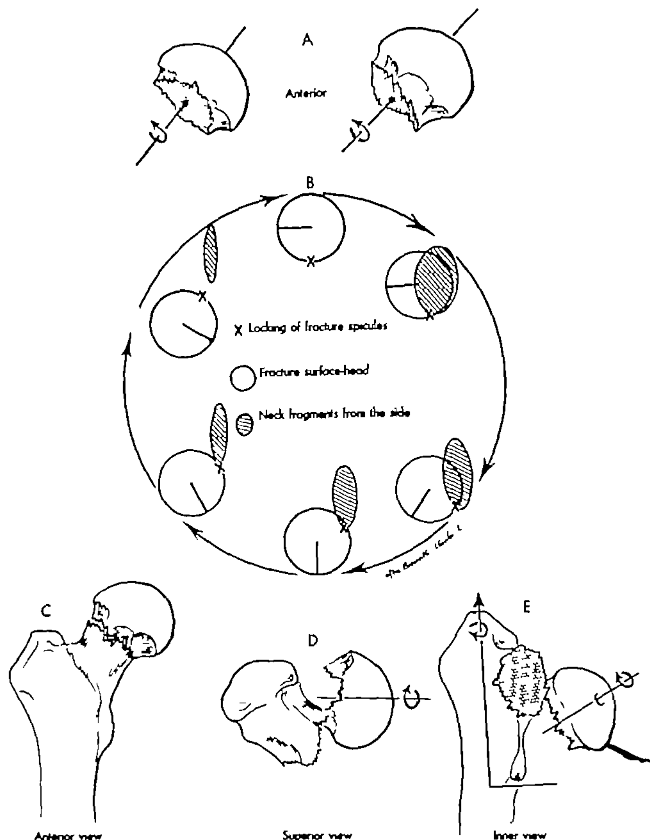


Fig 339 —Showing manner in which spicules of bone rotate the femoral head fragment Gentle traction should restore length before the fractured surfaces are apposed by internal rotation (From Cleveland M A and Bosworth D M Fractures of the neck of the femur A critical analysis of fifty consecutive cases Surg Gynec & Obst. 66 646 1938)

smaller one which is held only by negative pressure and the ligamentum teres femoris The friction coefficient of cartilage against cartilage is less than that of a skate runner on ice This is a very movable target indeed!

Small spicules of bone at the fracture site will often rotate the head during the development of the deformity that is com mon with the fracture Likewise these

of deformity of the proximal head frag ment. After traction has been applied in the line of deformity and length has been restored and if the trochanter does not come forward with internal rotation, the external rotation should be reassumed and the trochanter directly lifted forward be fore internal rotation is again attempted. This detail will often bring the distal frag ment forward to meet the proximal head

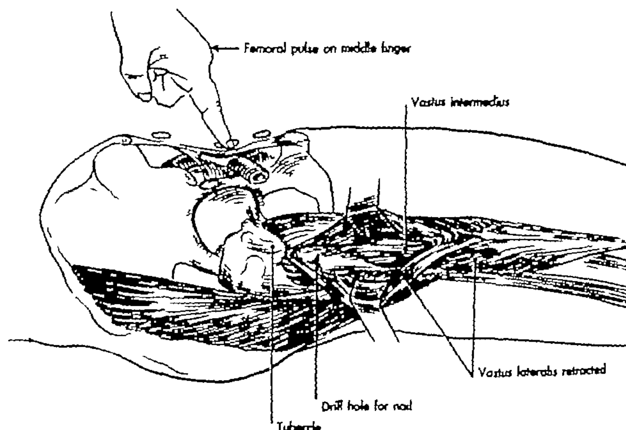


Fig 340 —Helpful anatomical guides in reducing and nailing fractures of the femoral neck. In palpating the anatomy around the hip the head of the femur may be marked on the skin by locating the femoral pulse at Poupart s (inguinal) ligament.

same spicules will rotate the head in any manipulative attempts that are not thoughtfully carried out. This rotation may or may not favor a good reduction. The spicules may also interfere with reduction A comminuted neck fracture with trans verse fragments may make it impossible to reduce the fracture properly by closed manipulation open reduction then be comes necessary

The first most obvious maneuver is to restore length to the extremity in the line

fragment without spinning the latter around. Thus the opposing fracture sur faces will be opposite one another and can be firmly fixed upon one another by inter nal rotation abduction and extension In this internally rotated abducted and ex tended position the muscle component forces are all in the line of the axis of the neck of the femur The fracture can be made more secure or impacted by acute flexion of the knee beyond a right angle This puts the rectus femoris muscle on

considerable stretch and pushes the femoral shaft upward and toward the acetabulum the component forces being toward the axis of the neck of the femur The internal rotation abduction and extension position keeps the iliopsoas muscle under tension and thus aids in maintaining reduction

After the manipulative reduction has been carried out, an evaluation of the position of the greater trochanter and its relationship to the anterior spine should be made and compared with the opposite side so that it can be told fairly accurately whether or not reduction has been satisfactory The heel test of Leadbetter to see whether or not reduction has been accomplished is an inaccurate evaluation for sometimes by reducing the fracture with the Leadbetter maneuver the neck of the femur can be displaced completely behind the head and internal rotation will maintain itself without an adequate lateral reduction. X ray films should be made in both anterior and lateral views with an assistant sitting "frozen" to the injured leg in a comfortable chair The anterior view is taken with the cassette directly under the hip and with the use of a tunnel cassette holder The lateral view is taken with the x ray tube at a right angle to Poupart s ligament and with the cassette held above the crest of the ilium between the crest and the ribs and perpendicular to the face of the x ray tube Adequate evaluation of the reduction can be made with these two views

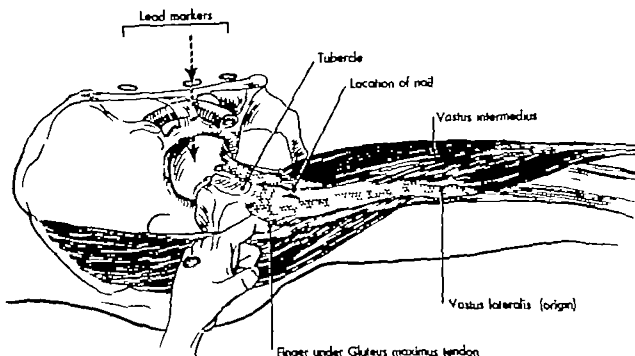


Fig 341 —Lead markers placed along the inguinal ligament serve as guides in the x rays for the angle of the nail The usual site of entry of the nail is as indicated. Anatomically this area is opposite the insertion of the gluteus maximus tendon and usually about 1¼ inches below the tubercle

External surface skin markings can be of great help in introducing the guide wire Three uniform markers are placed along Poupart s ligament with the central marker usually over the femoral artery and thus over the center of the head although too much abduction adduction or rotation may change this position slightly The use of these markers placed approximately 1 inch apart will guide in the alignment of the angle of the neck with the shaft

Specific Maneuvers to Improve Reduction —If the head fragment is in too

great a varus position a valgus position can be obtained without a full manipula tion, by simply increasing abduction using the hand as a fulcrum against the tro- chanter and applying counterpressure on the opposite pelvis This maneuver how ever should be done only after extending and slightly adducting the thigh maintain ing traction throughout the entire proce dure

If too much of a valgus position has been obtained in the reduction the leg can again be extended counterpressure ap- plied to the inner aspect of the upper thigh and the leg slowly adducted against this fulcrum with the addition of traction and a gentle rocking of internal and ex ternal rotation. This maneuver will convert too great a valgus position into a more normal angle

Anterior angulation of the neck at the fracture site can be changed by maintain- ing traction and bringing the leg (with the knee extended) into a neutral position, then using gentle flexion against a fulcrum (the heel of someone s hand) over the anterior neck and increasing the internal rotation. If this fails the manipulation should be continued with the maintenance of traction and the thigh adducted in right angle flexion directing the knee toward the opposite axilla.

If any of the above maneuvers do not result in an improvement of the alignment

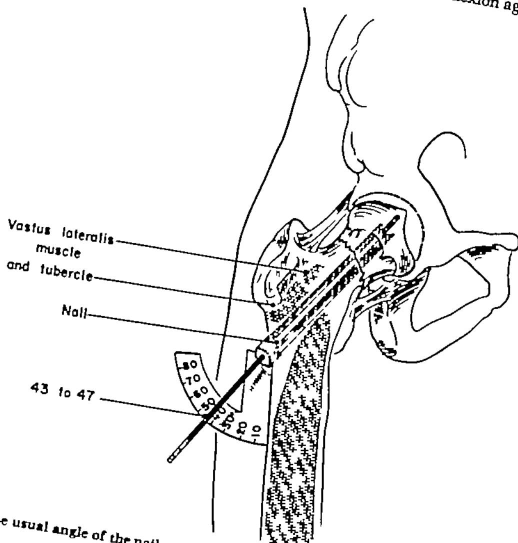


Fig 342.—The usual angle of the nail with the femoral shaft—between 43 and 47 degrees.

of the reduction a gentle release of the maintained position should be accom plished and a remanipulation in more flex ion and with longer traction should be car ried out—with the restoration of length as the primary factor the bringing of the trochanter forward as the secondary fac-

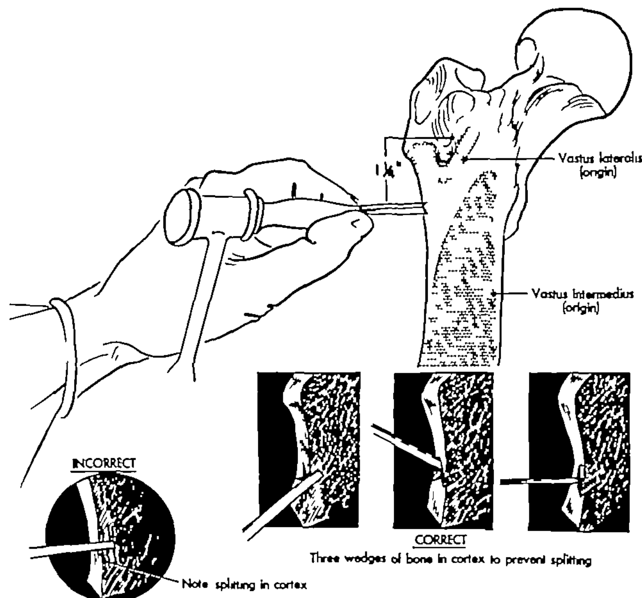


Fig 343 —Technique for nailing hip to avoid splitting of femoral shaft. Wedges should be cut in the cortex for the nail blades

tor and internal rotation abduction and extension as the final factor Acute flexion of the knee in the final position serves to lock the fragments firmly in their reduced position Multiple manipulations should be avoided If two or three gentle tries fail to reduce the fracture properly then open reduction is indicated The main key to all of these manipulations lies in the words of Ambroise Paré " to adjust that which is in default." The maintenance of adjustment now relies on internal fixation and for this the 3-flanged nail has been unsurpassed

Placement of the Nail —After reduction has been found to be satisfactory by means of adequate x ray films the nail ing can be carried out through a lateral incision. The placement of this lateral inci sion is aided by the anatomical knowledge of the tip of the trochanter and the lateral

shaft of the femur (Fig 340) A straight lateral incision down through the iliotibial band just below the tip of the trochanter and through the vastus externus muscle exposes the lateral shaft.

The point of entrance of the nail is usually approximately 1¼ inch below the vastus externus tubercle and just slightly toward the anterior cortex of the femur This point can be checked by its being opposite the superior margin of the tendon of the gluteus maximus as the tendon inserts into the linea aspera (Fig 341) These two points generally check within ¼ inch of one another The angle at which the nail is to be driven into the shaft can now be checked by this point and its relationship with the most optimum point on the skin markers the shadows of which will be cast on the x ray plate The angle which the neck makes with the shaft generally falls within 43 and 47 degrees with an average of about 45 degrees (Fig 342) If after checking these points with the skin markers and placing a wire between the skin marker and the point of the anticipated

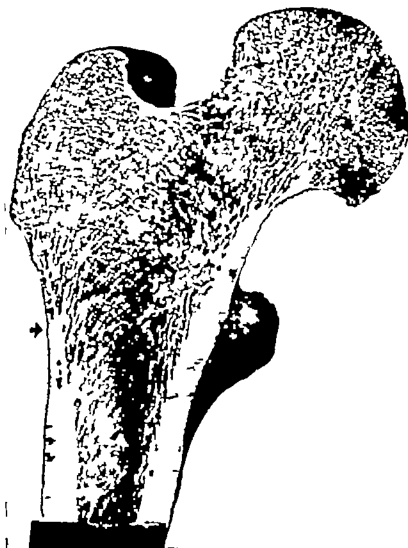


Fig 344 —Internal architecture of neck of femur Trabecular bone lends itself to compression by a 3-flanged nail and this compression results in increasing holding power over the surfaces of the blades of the nail. Notice the heavy lateral cortex at the site where the nail is to be inserted (*arrow*) To keep from splitting this cortex, small wedges of bone should be removed at this site before insertion of the nail.

entrance of the nail this angle does not approach 45 degrees checks by x rays *should be made of the points of entrance* Once this angle has been established a ¼ inch drill hole should be made through the outer cortex of the shaft. Small wedge-shaped openings into the cortex in line of the mallet aiming the wire at the most optimum point (in relation to the head) *that the markers have indicated In driving* this wire in a change in pitch is encountered as the wire crosses the fracture site and an increasing pitch gradually develops into a solid tone as the wire enters the

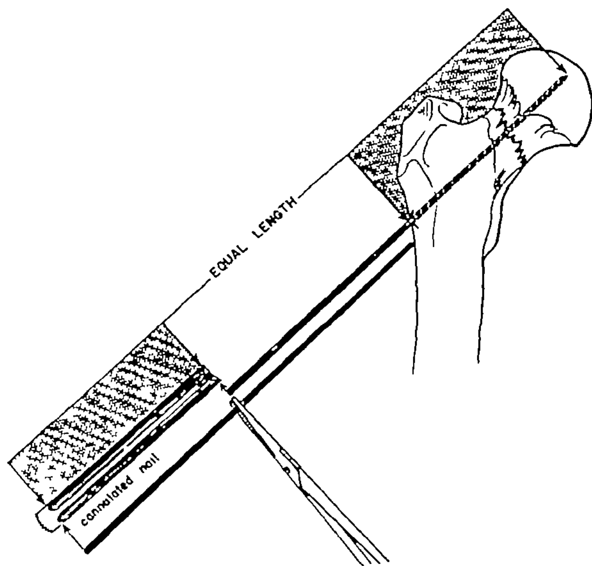


Fig 343 —Simple method for determining nail length. The simplest method is probably the best

with the 3 flanges of the nail are then made (Fig 343) The single blade of the 3 flanged nail is best directed upward (see Figs 330 and 344)

Following the making of these 3 small openings and the ¼ inch nail hole for the central portion of the cannulated nail the Kirschner wire can be drilled in In the line of the neck, by hand or by a gentle tap head The anteroposterior angle is easily outlined in this manner The lateral one is usually *parallel with the floor Once the* wire has been driven in it should be checked by both anteroposterior and lateral x ray films to be certain of its position

Position of the Nail.—An ideal reduction would be one that is perfect anatomically Acceptable reductions are those in

slight valgus position and in which the trabecular pattern does *not* cross the vascular channels of the neck A very minimal varus deformity is acceptable provided that the angle of the neck with the *shaft is not less than 45 degrees*

An ideal tract for the nail would then be one in which the nail goes through the inferior neck and into the head slightly below its center of gravity and slightly in the posteroinferior quadrant. With such a position any muscle pull or any very slight weight bearing would impact the fragments In any nail position which is less than a 45-degree angle or one which traverses the superior position of the neck and enters the inferior portion of the head the muscular and weight-bearing forces would tend to loosen the nail and have unfavorable shearing forces

PROPER LENGTH OF THE NAIL.—The proper length of the nail can be easily determined (Fig. 345) by the use of two Kirschner wires of the same length, one of which is driven across the fracture as a *guide and the other placed* on the lateral surface of the femur and projecting outward The difference between the length of the two wires indicates the proper length of the nail provided that the wire which has traversed the fracture line into the head is in the proper position and does not penetrate the cortex of the head

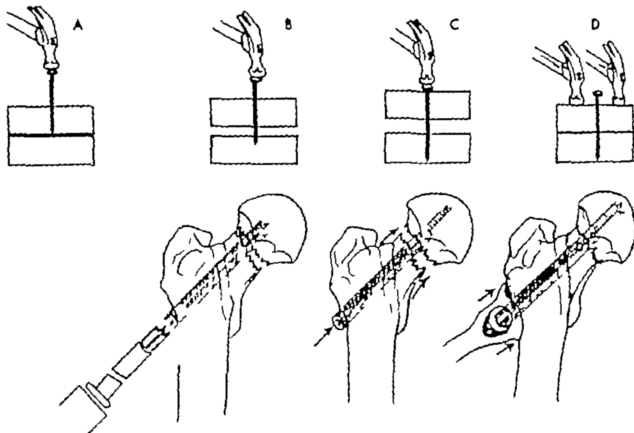


Fig 346 —Showing the importance of impacting a fracture of the femoral neck. As the nail is driven across the fracture line into the head (*A–C*) the fractured ends separate unless held together by some means Even then there is a tendency for them to separate so impaction is usually indicated as in *D*

IMPACTION —As the nail is being driven over the guide wire into the head a frequent check should be made by loosening the extension apparatus to be sure that the guide wire is not being driven into the pelvis Any change in pitch or in the ease with which the nail progresses is indirect

evidence that something is wrong The surgeon should stop and check all factors As the nail crosses the fracture line there is a change in pitch and the percussion note of the mallet becomes higher as the nail penetrates farther and farther into the head At any step in the procedure when there is doubt as to how the nail is entering the bone a check by x ray will prove valuable Once the nail has been driven into the flare at the base of the bone a film should be made to determine whether or not disimpaction has occurred and if so impaction should be carried out This can be done by regular impactors or by any apparatus that permits striking the cortex of the femur and thereby pushing the shaft toward the head fragment Impaction occurs when the nail protrudes a little after this procedure When this occurs the surgeon should not strike the nail again (Fig 346) such a procedure would undo the impaction Impaction should be carried out when x ray evidence indicates in either view that there has been separation of the fracture line by the process of nailing It is not necessary to impact if separation has not occurred A gentle clinical test of the security of the nailing and for reassurance regarding the efficiency of the procedure should be carried out while the patient is still under anesthesia (Fig 347)

Prognosis in Fractures of the Neck of the Femur

The prognosis of the fracture of the neck of the femur is influenced partly by mechanical factors and partly by physiological factors—for example by the unknown amount of trauma to the circulation and by the unknown reparative ability of the individual patient. The manipulative efforts of the surgeon probably also affect the prognosis more than is generally appreciated.

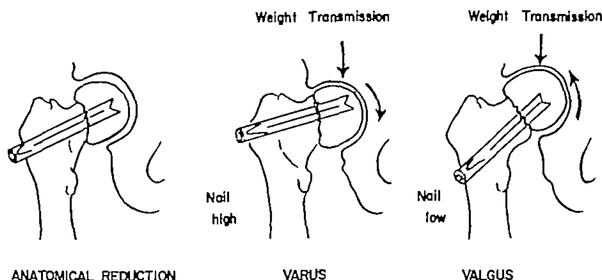


Fig 347 —Showing acceptability of both anatomical and valgus positions of the head of the femur The varus position however is not acceptable and will usually result in nonunion unless it is protected through a very prolonged period of non weight-bearing. Even after union the joint is almost certain to develop traumatic arthritis

From the mechanical standpoint alone a prognosis can be made fairly accurately along the general lines of the type of injury and the direction of the fracture line In brief the healing of the fracture seems to be almost proportional to the direction of the fracture line Those fractures which have a more horizontal line in regard to the direction to weight bearing are more likely to heal than those which have a vertical line In fact Pauwels in his work on the mechanical problem of the fracture of

the hip gives statistics to help substantiate this view showing that fracture lines on the horizontal tend to unite in as many as 90 or more per cent of cases whereas those with a vertical fracture line are likely to go on to nonunion in as high a percentage of cases as 90 per cent (Fig 348)

In large general reviews of fractures of the neck of the femur treated by internal fixation the over all figures in round numbers show that approximately 70 per cent the favorably impacted neck fractures in valgus position have resulted in what appears to be bone union in much less time (see Figs 338 and 351)

COMPLICATIONS —Even though bone union may occur the complications of aseptic necrosis of the femoral head and traumatic arthritis of the hip may develop. (For the treatment of aseptic necrosis which develops after healing see page 450)

The mortality rate in patients with frac

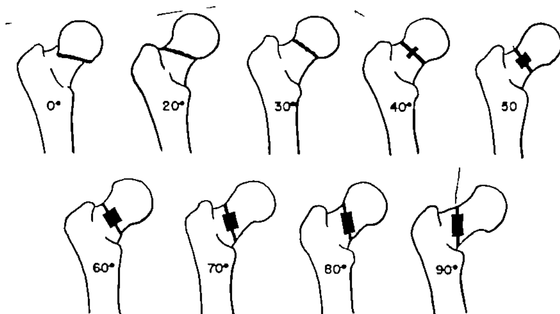


Fig 348 —The range of fracture lines of the femoral neck—from almost horizontal to vertical Fractures which are nearly horizontal seem more likely to unite than do those which are vertical However the vertical fractures require more accurate reduction extreme care in placing the nail and prolonged protection from weight bearing during convalescence If these principles are followed the percentage of bone union of the vertical fractures will compare favorably with that of the horizontal fractures

of the fractures form bone union (Fig 349) It is also generally agreed that more than a year should elapse before it can be accurately determined whether or not there is bone union Removal of the internal fixation agent before the end of a year has frequently resulted in a dissolution of the healing process even though x ray films were interpreted as showing adequate bone union The development of callus is a very slow process and the consolidation of the fracture certainly requires a year or more (Fig 350) Fractures in the more horizontal plane however such as those seen in ture of the neck of the femur has been reduced since the introduction of internal fixation At present, most of the patients survive such a fracture provided that it is treated as a relative surgical emergency A statistical study of the mortality rate in elderly people is of course a difficult thing to interpret because possibly as high as 25 per cent of these people might not ordinarily survive a year whether or not they had a fractured hip It is safe to say however that death due to the fracture itself is now a minor part of the complications. Surgical infections pulmonary infarction



Fig. 349 —Illustrating the importance of the use of x ray films as a guide in nailing the fracture A, anteroposterior and lateral x ray films for reduction of a displaced fracture Adequate films are a necessity to be sure of the reduction. B films required for checking during placement of nail (or other form of internal fixation agent) C checking by x ray also a necessity before weight bearing is allowed



Fig 350 —This position of valgus appeared to be satisfactory At the end of 1 year the patient had no symptoms At 13 months she had pain and at 18 months a large area of aseptic necrosis had occurred Notice that in the anteroposterior view (left) the stress lines in the head fragment lean outward from the vertical This feature may be a prognostic sign of the complication of aseptic necrosis or nonunion Position in lateral view (right) appears satisfactory At 6-year follow-up position was still satisfactory and there was no sign of aseptic necrosis in the femoral head This reduction was questioned but the blood supply apparently returned to the head fragment



Fig 351 —Successful nailing in old fracture. A, an old fracture as evidenced by the rounded fracture ends B several months after nailing evidence of consolidation at the fracture line. C, 3 years after removal of nail hip function essentially normal. D 5 years after fracture; modeling of neck apparent.

and other complications (Fig 353) are of course to be expected in the elderly but no more so than in any other type of surgery

Surgical After-Care

The groundwork for the development of bedsores is laid while the patient waits—on the floor after his injury on the litter on the x ray table and on the operating table or just lying in bed too deeply medicated Frequent changes of position are necessary to avoid this disaster

Elderly patients with fractures need more attention to detail and bed care than do other types of surgical cases The institution of early nursing care with careful watching and attention to detail will be



Fig 352.—A, anteroposterior and lateral views of fractured hip with nailing that was considered acceptable B at 6 weeks evidence of slipping in anteroposterior and lateral views C downward rotation of head in anteroposterior view and posterior rotation of head in lateral view D three views showing original fracture (*left*) what appeared to be a good nailing (*center*) and redisplacement to the original position without weight bearing (*right*)

rewarding Early active muscle setting exercises and frequent changes in position in bed are essential to recovery

After the soft tissues are healed (at the end of 3 or 4 weeks) and the patient has made adequate recovery in the function of the muscles of the extremity it is possible to remove the leg from the splint or traction and allow moving around in bed. A gradual resumption of activities to a bed-and-chair existence is instituted Where indicated, the patient should if possible be taught how to use a walker or crutches At the end of 4–6 weeks and as symptomatic improvement indicates a gradual increase in the amount of activities and partial or supported weight bearing are instituted In general the use of crutches is advisable for at least 6 months. A cane is recommended as long as there is any limp. The discarding of all types of supportive apparatus comes when the physician is sure that the gait is proper and the fracture is healed as determined by x-ray films.



Fig 353 —Top anteroposterior and lateral views showing nailing of fractured hip of 93-year old patient Because of the patient's age this nailing was accepted Bottom 5 years later Poor positions of fragments should not be accepted—regardless of age

Exercises in Bed

Exercises in bed consist of simple anterior tibial pull toe pressing and heel-cord stretching quadriceps setting internal and external rotation of the hip abdominal and gluteal setting and hamstring setting —in other words using all of the muscles in the extremity These exercises are not confined to the injured leg but are carried out by the other leg as well The patient is also taught how to use the overhead sus-

rotation In thin subjects this may produce peroneal palsy

4 Excess weight—over 10 pounds of pull. This may cause skin damage To avoid such damage as large an area of skin as possible should be used for traction

5 Incorrect position of pillow The pillow must be placed under the full length of the calf not "balled up" under the knee

6 Incorrect placement of the footpiece The footpiece must not rest against the bedframe

7 Failure to elevate the foot of the bed for countertraction. Low shock blocks should be used to elevate the foot of the bed.

After the traction is applied the physical status of the patient should be evaluated promptly and any deficiencies corrected including the correction of possible dehydration

The cardiac and pulmonary condition of the patient also requires attention. Rapid digitalization has not proved too satisfactory in the Fracture Clinic at the Massachusetts General Hospital Digitalization for several days gives a more satisfactory and prolonged effect.

Preparation of the operative area is not done until after anesthesia has taken effect.

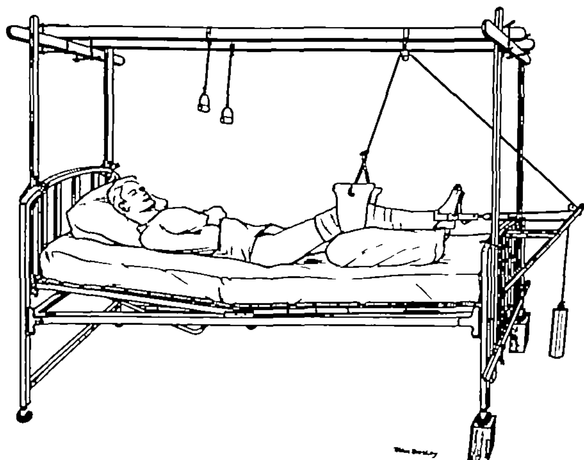


Fig 354 —Russell traction.

Types of Extracapsular Fractures

The extracapsular fractures may be subdivided into the following types (1) intertrochanteric (2) pertrochanteric and (3) subtrochanteric

In intertrochanteric fractures the fracture line passes upward and outward along the intertrochanteric line generally the trochanters are not involved Variations in these fractures are determined only by the deforming force that continues to act after fracture producing external rotation and

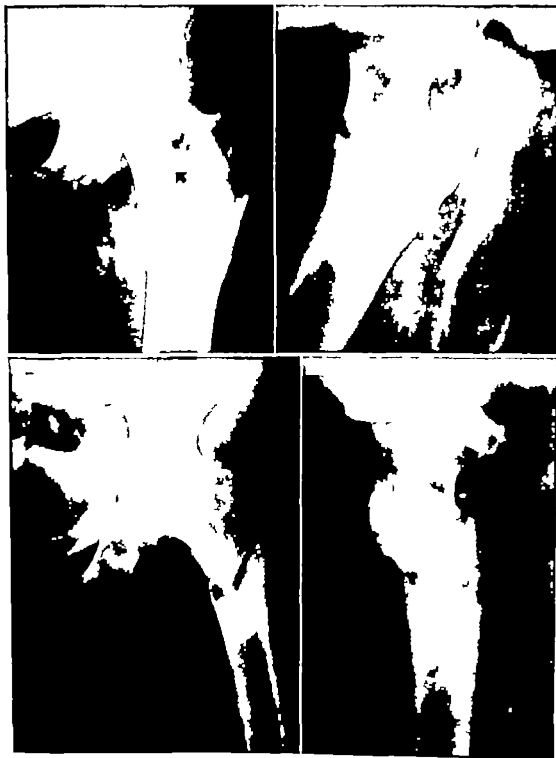


Fig 355 (top) —Type 1 simple linear intertrochanteric fracture without displacement *Left* anteroposterior view (arrow points to fracture) *Right* lateral view

Fig 356 (bottom) —Type 2 pertrochanteric fracture with varus deformity and slight widening at fracture line indicating external rotation of the lower fragment The lesser trochanter is intact *Left* anteroposterior view showing fracture line passing into the trochanteric block *Right* lateral view not clear enough to tell whether the greater trochanter is split vertically Important to look for this!

Kirschner wire through the tibial tubercle is advisable The threaded wire is effective in preventing sliding of the wire in the osteoporotic bone so frequently found in aged patients

Operative Treatment

At the Massachusetts General Hospital the operative treatment is the same for all of the extracapsular fractures It consists of the use of a nail plate combination the length of the plate depending on the length of the fracture line Occasionally reinforcement with a Parham band may be indicated. On several occasions a Küntscher nail has been used for transverse subtrochanteric fractures (Fig 361 C)



Fig 361 —Transverse subtrochanteric fracture in Paget s disease A anteroposterior view showing varus deformity of proximal fragment B lateral view showing anterior angulation of proximal fragment at fracture site C fixation of fracture by a Küntscher nail with solid union. Note the varus position of the head.

The patient is placed on a regular operating table with a cassette tunnel under the hips It is important to have the affected hip well over to the side of the table because occasionally it may be necessary to nail the fracture with the leg in external rotation. This is an almost impossible task if the leg is toward the center of the table. A fracture table may be used. The leg on the fractured side is draped free so as to facilitate manipulation later

The incision is made laterally from the tip of the trochanter distally for a distance of 8–10 inches The dissection is carried down to the fascia lata, which is split about 1 inch anterior to the linea aspera. The vastus lateralis muscle is split by blunt dissection about 1 inch anterior to the linea aspera. Anterior reflection of the vastus lateralis is facilitated by curving the incision forward into the tendinous attachment of the muscle to the greater trochanter Subperiosteal reflection is then done and the muscle held forward by a Bennett retractor The linea aspera is split by a knife sufficient to allow the tongue of a Bennett retractor to be inserted

Adequate reflection of the upper reaches of the vastus lateralis and intermedius muscles will usually expose the fracture site anteriorly Palpation of the fracture will disclose the situation to be remedied.

Generally the fracture to be dealt with is one in which the distal fragment is exter nally rotated and the trochanter shows some degree of comminution Not infrequently the posterior portion of the greater trochanter may be split vertically and rotated externally and posteriorly as a free fragment.

Reduction is obtained by traction on the leg in slightly flexed position plus rotation

A word of caution about the use of rota tion In an unimpacted extracapsular frac and then to secure reduction an assistant applies traction with flexion or abduction or both

It may be necessary to place the shaft fragment in considerable external rotation in order to appose it to the greater trochan ter which has been pulled into external rotation by the short external rotators In order to nail the hip in this position of ex ternal rotation the patient should be placed well to the side of the table

This situation can be met by placing one

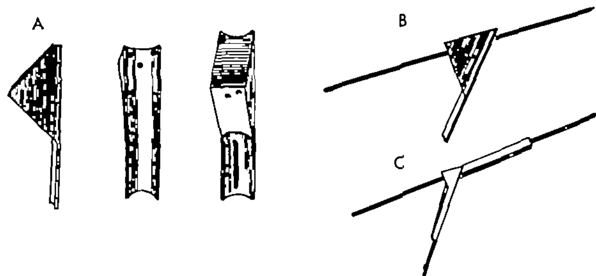


Fig 362.—Jig for Jewett nail. A, three views of jig. Three holes are drilled in the jig to form an angle of 130 degrees corresponding to the angle between the nail and plate elements of the Jewett nail. B guide wire inserted through hole in jig C jig removed and Jewett nail placed over guide wire

ture the shaft of the femur rotates about its own axis whereas in the impacted extracapsular fracture and in the femoral neck fracture the shaft rotates on an ec centric arc and the greater trochanter can be felt describing such an arc In femoral neck fractures internal rotation of the shaft is used to close the fracture line Since in the comminuted extracapsular fractures the shaft revolves around its own long axis on rotation the surgeon must be alert to the possibility of closing the frac ture line in front and at the same time opening it too much posteriorly This over reduction is prevented by placing the fin gers of one hand in the subtrochanteric bursa while rotation is performed The optimum position of rotation is determined hand in the subtrochanteric bursa behind the greater trochanter and lifting the trochanteric block forward. By this maneuver the guide wire can be passed into the neck in a more horizontal plane

A pilot hole is drilled into the cortex of the shaft about 1¼–1½ inches below the vastus externus line With the fracture reduced and held secured by a clamp (if that is possible) a jig is placed against the femoral shaft and a ³⁄₃₂-inch guide wire is passed through one of the holes in the jig up into the femoral neck. The wire may be drilled or tapped in by hand If the wire is well centered it may be pushed in by hand for 3–3½ inches without meeting appreciable resistance

The holes in the jig are fixed at such an

angle that the wire passed through one of the holes will form an angle with the shaft equal to that of the Jewett nail plate (130 degrees) (Figs 362 and 363) The position and depth of the wire should be checked by anteroposterior and lateral x ray films If the position of the wire is satisfactory a second wire of the same length is placed against the first, with the tip of the second wire touching the edge of the pilot hole The length of the second wire projecting laterally beyond the end of the first wire represents the length of wire in bone and is an accurate measure of the length of nail to be used (p 441 Fig. 345)

The length of the nail should be so calculated that the nail will project just beyond the head neck junction of the femur This will allow for secure fixation in the head and will prevent the complication of overpenetration of the nail

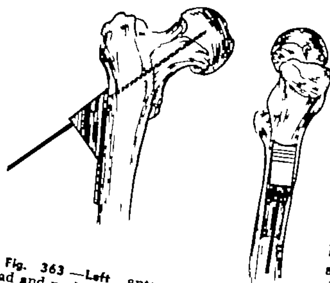


Fig. 363 —Left anteroposterior view of head and neck of femur showing jig in place with guide wire Jig is placed on lateral aspect of femur with center hole at the point of election usually 1¼ inches below the vastus externus line Pilot hole is made in bone at this point. Jig is placed over the hole and a guide wire passed into the head A Jewett nail can then be driven over the wire and its plate will fit flush against the femoral shaft. Right lateral view showing position of jig and guide wire Holes posterior and anterior to the center allow for change of wire in lateral plane

The Jewett nail plate is next driven home so that the plate section lies flush against the femoral shaft, to which it is then secured by screws The plate section may vary in length from 3 to 6 inches depending on the extent of the fracture into the subtrochanteric region. When driving in a Jewett nail plate the surgeon should watch for the tendency of the blade to rotate anteriorly

Technique varies in the preparation of the cortex for nailing Some surgeons prefer to ream out a hole while others cut slots for the blades of the nail.

Fixation of the apparatus to the shaft is mandatory in all except the simplest undisplaced extracapsular fractures where a nail alone may occasionally be used with success

Extensive stripping of the muscles should be avoided and it is preferable to accept a less-perfect reduction rather than deprive multiple fragments of their blood supply

The avulsed lesser trochanter should be fixed if it can be reached without extensive dissection. The displaced lesser trochanter heals with abundant callus (Fig 364)

Check up films are taken before closing the wound.

The leg is bandaged from toes up to the waist with a pressure pad on the gluteal bursa region. One or more blood transfusions should be given if indicated. Then the patient is returned to bed and is placed in Russell's traction with 2 pounds of weight (4 pounds of pull)

Postoperative Care

After treatment is an individual problem. If the patient's condition is poor and if good stability has been obtained by the nail and plate the patient may be lifted out of bed into a chair the following day Otherwise the patient is allowed to lie in bed and to move from side to side and he is encouraged to exercise the legs and to do deep breathing If the bones are of good quality mobilization is allowed at the end of 2 weeks If the osteoporosis is marked caution must be used because overactivity will cause the nail to cut through the fem-

oral neck. Weight bearing particularly in the patient with osteoporotic bone should be delayed for 3 months

Taylor Neufeld and Nickel have pointed out that in extracapsular fractures open reduction delays repair so that adequate repair may not take place for 4–6 months Some surgeons think in terms of the strength of the apparatus rather than in terms of the strength of bone

Crutches are used until muscle power in the abductors is restored to normal



Fig 364 —Left displaced lesser trochanter filmed 1 year postoperatively Note massive cal lus formation around the displaced trochanter Right oblique view showing solid union

Complications

Complications Due to Structural Failures —Prior to the use of the Jewett nail plate most of the structural failures were due to the separation of the nail-plate combinations The bolts loosened occasionally a bolt broke and on rare oc casions a plate fractured at the gooseneck where it had been reshaped repeatedly to fit into the nail

Loosening of the bolts was due to sev eral factors (1) tightening the bolts with a screw driver instead of a wrench (2) variations in the depth of the well in the nail head and (3) too short bolts Figure 365 shows the separation of plate from nail

The Jewett nail plate has proved highly satisfactory at the Massachusetts General Hospital and the various complications associated with the separate nail plate combination have been eliminated Two Jewett plates have broken (Fig 366) and one Jewett nail

Complications Due to Errors in Technique.—The following errors in tech nique are responsible for complicating the healing of the fractures

1 Improper preparation of the nail bed in the cortex Such an error may cause fracture of the femoral shaft at the point of nailing because the milled portion of the butt of the nail acts as a wedge to split the bone (Fig. 367)

2. Overpenetration of the nail The end of the nail should reach only to the head neck junction

3 Breaking of screws The breaking of screws may result from fixing the plate to the shaft under tension which is com monly done by driving in the nail and then abducting the femoral shaft to fit against the plate Unless the fracture is free the screws will be under tension and may break.

4 Cutting out of the nail. This can happen in osteoporotic bone with early weight bearing and should be considered as a possibility if the nail is off center in the lateral view

5 *Broken drill points* (Fig 367)

6 Inadequate fixation (Fig 368)

7 Loosening of bolts (Fig 365)

CLINICAL COMPLICATIONS —The common clinical complications are thrombophlebitis vascular accidents diabetes and cardiac failure

1 Thrombophlebitis is an ever present complication despite efforts at early mobilization and bandaging of legs

Treatment of this complication has moved in cycles For several years vein ligation held sway An analysis of 100 consecutive cases proved quite illuminating In this particular series 49 patients had vein ligations 51 did not. Fifty-one patients had internal fixation 49 were treated by traction. Of the deaths in the series 5 could be ascribed to pulmonary embolus In these 5 cases 3 patients had the veins tied and 2 did not. The ligations were done before during and after the nailing

Because it was felt that vein ligation had not proved its value during the past 10 years anticoagulants have been used when indicated These should be employed with caution in older people or serious bleeding into the thigh may occur

2 Vascular accidents are a common complication in the aged.

3 Diabetes should be looked for and brought under control before surgery In one recent year 3 cases of major sepsis occurred in patients with severe cases of diabetes

4 Cardiac failure was listed as a frequent complication—a final complication in both operated and nonoperated cases.



FIG 365 (left) —Separation of plate from nail due to loosening of the bolt. Note the cannulated bolt the separation of the combination and the loss of position also how avulsed lesser trochanter has healed to form a buttress

FIG 366 (right) —Fracture of Jewett plate through screw holes Note varus position of the fracture

Metallic appliances will separate or break if they are applied under stress



Fig 367 (left) —Fracture of lateral wall of femoral shaft caused by nail Note also broken drill point at lower end of the Jewett (nail) plate

Fig 368 (right) —Comminuted subtrochanteric fracture treated by screw fixation Healed in varus position but only after prolonged traction in bed

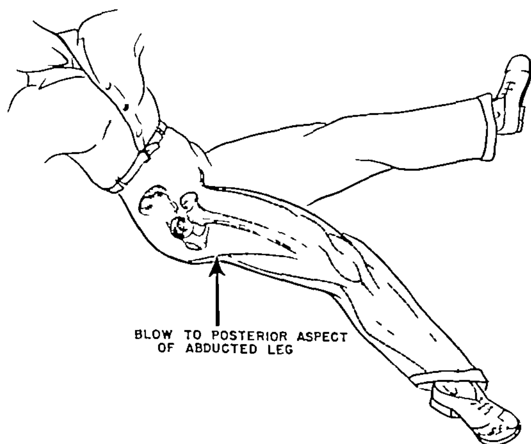
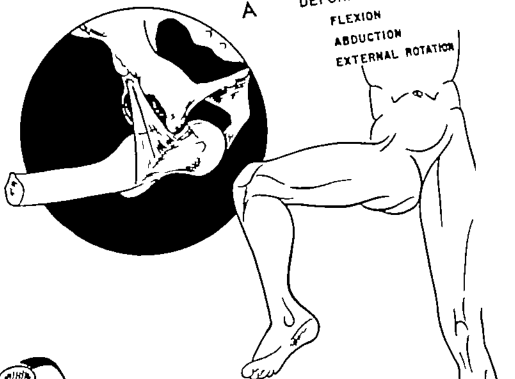
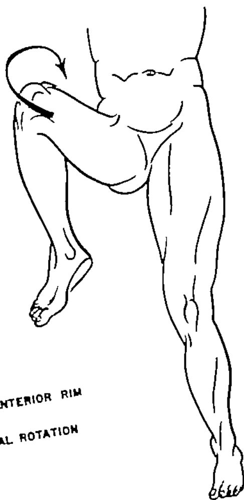


Fig 369 —Mechanism of anterior dislocation of hip







REDUCTION
TRACTION IN FLEXION
LIFTING HEAD TO ANTERIOR RIM
OF ACETABULUM
■EDUCTION BY INTERNAL ROTATION

—Anterior dislocation of hip A typical deformity B closed manipulation (co

Each case of an extracapsular fracture is a problem in itself and statistics are valuable only in that they indicate trends Over the years there has been a gradual decrease in mortality At present the mortality rate averages about 8 per cent.

There has been a steady increase in the use of open reduction with a correspondingly lessened morbidity

DISLOCATIONS OF THE HIP AND FRACTURES OF THE ACETABULUM

The modern phase in the management of dislocations of the hip dates from the publication in 1869 of Henry Jacob Bigelow's work on the hip Bigelow demonstrated that complete flexion of the hip and thus relaxation of the anterior iliofemoral ligament (Y ligament of Bigelow) was necessary in order to reduce the majority of posterior dislocations of the hip

Information is available on 107 dislocations of the hip and acetabular fractures that have been treated at the Massachusetts General Hospital (Tables 14–16) during the past 20 years Follow-up studies have been completed on 75 (70 per cent)

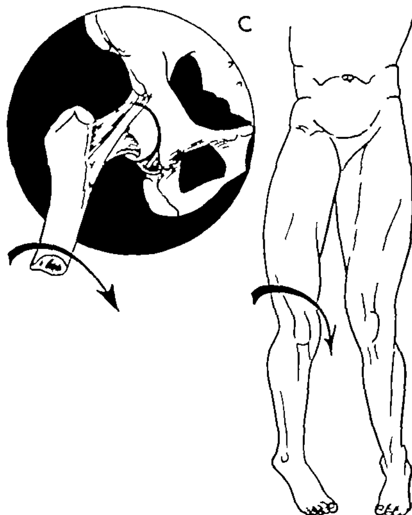


Fig 370 (cont) —C reduction completed by extension of leg.

Anterior Dislocations of the Hip

Mechanism of Injury —The most frequent cause of anterior dislocation of the hip is a blow to the posterior aspect of the abducted and externally rotated thigh (Fig 369) The blow is usually caused by a fall from a height

DIAGNOSIS —The typical deformity of the patient with an anterior dislocation of the hip is shown in Figure 370 *A* The degree of deformity depends on the position of the femoral head The femoral head may be palpated anteriorly

X RAY EXAMINATION —An anteroposterior film of the pelvis is usually sufficient to establish the diagnosis of an anterior dislocation (Fig 371)

TREATMENT —Anterior dislocations are easier to diagnose and easier to reduce than are posterior dislocations All anterior dislocations in the series were successfully reduced by closed manipulation

Technique of Closed Reduction —Figure 370 *B* and *C* illustrates the closed reduction of an anterior dislocation of the hip The procedure follows

1 With the patient anesthetized and lying supine on the floor traction is applied to the hip in the position of deformity —that is in flexion and abduction.

2 When the femoral head feels free and is judged to be replaced on the anterior rim of the acetabulum traction is applied in a more vertical position

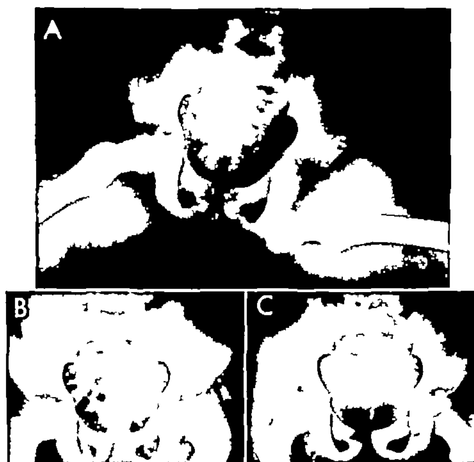


Fig 371 —Anterior dislocation of left hip of 9-year-old boy the result of a coasting accident. A immediately after accident. B follow up at 1 year C follow up at 2 years excellent result.

TABLE 14 —ANALYSIS OF 107 DISLOCATIONS OF THE HIP AND FRACTURES OF THE ACETABULUM

Dislocations of the hip without acetabular fractures		27
Anterior dislocation	3	
Posterior dislocations	24	
Posterior dislocations of the hip with acetabular fractures		23
Central dislocation (*intrapelvic protrusion*)		25
Acetabular fractures comminuted without dislocation of the femoral head		17
Acetabular fractures, linear undisplaced		15
Total		107

3 Internal rotation usually completes the reduction

Postreduction films are taken to determine the position of the femoral head and the presence or absence of loose bodies in the joint since these have a direct bearing on prognosis

TABLE 15 —ANALYSIS OF 75 HIP DISLOCATIONS

Type			
Anterior dislocation	3 (4%)		
Posterior dislocation	47 (63%)		
(23 [49%] with fracture of the posterior acetabular rim)			
Central dislocation	25 (33%)		
Position of Femoral Head in Posterior and Anterior Dislocations			
Head in high position	(63%)		
Head in midposition	(25%)		
Head in inferior position	(12%)		
Side of Body			
Right	36		
Left	35		
Bilateral central dislocations	2		
Sex			
Males	54 (72%)		
Females	21 (28%)		
Age	Dislocation		
	Anterior	Posterior	Central
Average age	25 yr	28 yr	47 yr
Youngest	12 yr	9 yr	11 yr
Oldest	35 yr	61 yr	82 yr

POSTERIOR DISLOCATIONS OF THE HIP (WITHOUT FRACTURE OF THE ACETABULUM)

MECHANISM OF INJURY —A posterior dislocation of the hip is usually produced by a direct blow to the flexed knee (Fig 372) This injury is more traumatic than is an anterior dislocation In addition to rupture of the posterior joint capsule the short external rotators of the hip (the piriformis gemelli, and the obturator internus muscles) are usually perforated or damaged Of the posterior dislocations 21 per cent required an open reduction

DIAGNOSIS —A patient with a posterior dislocation of the hip presents a typical deformity (Fig 373 *A*) Bigelow observed that this position was due to the intact iliofemoral ligament and noted that when the ligament was ruptured, the characteristic deformity of the extremity was not present

The extremity is usually shortened adducted and internally rotated The extremes of this deformity depend somewhat on the high middle or low positions of the femoral head The head of the femur may be palpated posteriorly in thin persons The lesser trochanter cannot be seen by anteroposterior x ray examination on the dislocated side

A posterior dislocation may be confused at times with a fracture of the femoral neck or of the femoral shaft. Sir Astley Cooper called attention to this in 1825 The deformity of the dislocated hip is "fixed" that is the position of the extremity cannot be corrected If correction is attempted the patient experiences acute pain and possibly sciatic nerve irritation On the other hand a deformity of the femoral neck fracture can be gently manipulated into a corrected position. This may be true also for fractures of the femoral shaft

TABLE 16 —ANALYSIS OF 80 ACETABULAR FRACTURES

Incidence		
Acetabular fractures associated with dislocation of the hip		48 (60%)
Posterior rim fractures with dislocation	23	
Central fractures with intrapelvic protrusion	25	
Acetabular fractures comminuted without dislocation of femoral head		17 (21%)
Acetabular fractures linear undisplaced		15 (19%)
Total		80
Sex		
Males outnumbered females 2 to 1		
Side of Body		
Right		59%
Left		41%
(Bilateral in 2 instances.)		
Age		
Average for group		45 yr
Oldest		82 yr
Youngest		5 yr

Signs of sciatic nerve injury should be noted. In addition the knee should be examined for possible patella or tibial table fractures

Fig 373 (cont) —C reduction completed by extension of leg





Fig 374 —Left view of posterior dislocation of right hip (dashboard injury) showing posterior and high position of femoral head Right follow-up 7 years later no joint changes Complete range of motion and no pain

"rocked" forward and backward so as to free the head from the rotator muscles and posterior capsule In some instances it is helpful to flex the hip beyond 90 degrees pointing the knee toward the opposite shoulder When it is felt that the head has been freed posteriorly and elevated to the posterior rim of the acetabulum one of two maneuvers may be used (1) further internal rotation to reduce the head into the acetabulum or (2) gentle external rotation and extension of the thigh which will tense the Y ligament and thus lift the head forward into the acetabulum

All manipulations should be carried out gently A rough manipulation with sudden and very forceful reduction of the femoral head may cause irreparable damage to the cartilage of the head After reduction a test for stability of the hip should be carried out Very careful postreduction x ray *films should be taken to determine whether* there is any visible bone injury to the femoral head or acetabulum or free bone fragments in the joint This information is very important relative to prognosis

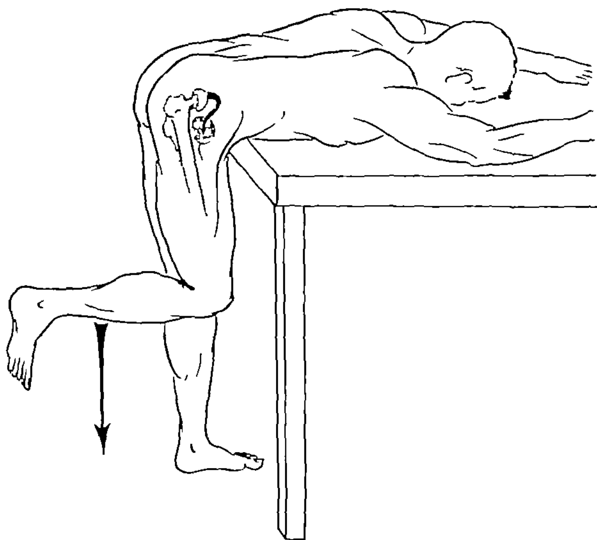


Fig 375 —Prone technique of reduction

Stimson Method (Prone Method) — This method of reduction (Fig 375) has perhaps been used too infrequently It is a safe method.

The patient is placed face down on a table with the *injured hip flexed at 90* degrees or more over the end of the table Firm downward pressure is applied to the flexed leg—that is the thigh at 90 degrees and the knee at 90 degrees A gentle rock

ing motion may be helpful in this maneu ver as in the Bigelow procedure In thin patients the operator may apply gentle pressure directly to the femoral head. By gradually increasing the downward trac tion on the leg and with slight increase in internal rotation flexion and adduction the operator can position the head onto the posterior rim of the acetabulum and reduc tion will be completed

In the management of a dislocated hip it is well to keep in mind the possibility of a concomitant fracture of the femoral shaft Such a combination occurred in 4 per cent of 107 hip dislocations and acetab- ular fractures at the Massachusetts Gen- eral Hospital. It is interesting to note that Bigelow discussed this condition in 1869 and clearly stated that when this combi nation occurs "splinting" of the femur and a careful manipulation with manual pres- sure on the femoral head should success- fully reduce the hip His advice was sound and the method should be tried. If the ma neuver is unsuccessful however then sta bilizing the femur by means of an intra medullary nail should expedite successful closed reduction of the hip

TREATMENT BY OPEN REDUCTION — The indications for open reduction are (1) repeated unsuccessful attempts at closed reduction (2) late or old disloca tions and (3) a dislocation associated with unreduced fractures of the acetabu lum or injury to the sciatic nerve (this will be considered under Fractures of the Ace tabulum)

The purpose of the maneuver should be to return the head of the femur to the acetabulum with as little trauma as pos- sible If a second manipulation proves nec essary the surgeon should be prepared to proceed with open reduction of the hip Open reduction may be performed from the anterior lateral or direct posterior ap- proach to the hip (see pp 480-485 Surgi cal Approaches to the Hip) The approach will depend on the preference of the sur geon Each approach has its indications and advantages

AFTER-CARE —Follow-up studies indi cate that the method and schedule of after-care bear little relation to the fi functional result of the uncomplicated d located hip It seems important, howeve to outline for after-care a schedule that physiological and reasonable With this h mind it may be well to point out the following

1 The dislocated hip may be consid- ered stable once reduction is accomplished, assuming that there is no fracture of the acetabulum.

2 Injury to the posterior capsule and short rotator muscles should heal within 3 weeks During this time painful motion and pressure on the posterior hip st tures should be avoided.

3 Early active and passive joint r tions carefully performed should stim late nourishment to the hyaline cartilag of the femoral head by altering the osmoti pressure of the joint fluid.

The following schedule is suggested

1 Bed rest for a period of 3 weeks

2. During this time early active and passive motion of the hips and muscle- setting exercises These may be started a few days after reduction and increased as tolerated by the patient

3 Partial weight bearing on crutches for a period of 3 months A longer period of partial weight bearing may be indicated, depending on the patient's progress.

4 The performance of light work by the patient 4–6 months after injury and full activities 10–12 months after injury

5 Follow up of the case The patient should be followed carefully and examined periodically with x ray and physical exam- inations for several years after injury

FRACTURES OF THE ACETABULUM

MECHANISM OF INJURY —The most fre- quent cause of the fractures of the acetab- ulum seen at the Massachusetts General Hospital was a direct blow to the tro- chanter (56 per cent) (Fig 376) A direct blow to the flexed knee ("dashboard in jury") accounted for 29 per cent (Fig 372) The remaining fractures (15 per cent) were caused by a variety of injuries

the exact mechanism of which was not clear

In general, if the hip is flexed and the blow is received from the flexed knee the *impact of the head of the femur* is against the posterior acetabulum If the hip is in extension the force is against the superior acetabular shelf When the impact is directly against the trochanter a central fracture of the acetabulum may result

posterior roentgenograms of the acetabulum

TREATMENT —Patients with linear acetabular injuries may be expected to do very well on a schedule of initial rest and hot packs to the hip plus early active motion in bed Partial weight bearing can be started within 1–3 weeks and continued for 6–8 weeks Light activities may be tolerated at the eighth or tenth week, and full

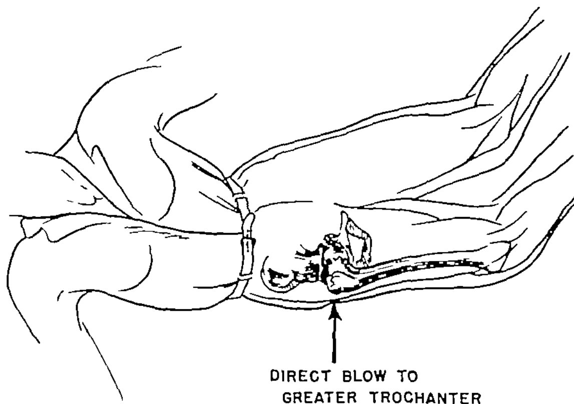


Fig 376 —Mechanism of intrapelvic protrusion.

activity at the third or fourth month The responses of the patients to a schedule such as this will vary markedly Some patients will be active and pain free others may respond more slowly

Rhythmic exercises bicycle riding and swimming are very beneficial Running and jumping should be avoided until there is healing of the fracture

The prognosis for this type of acetabular fracture in general is excellent

The most important quadrant of the acetabulum in relation to stability of the hip is the posterior quadrant. The most important in relation to weight bearing is the superior quadrant The inferior quadrant may be considered a "silent" area since it plays little part in either weight bearing or stability

Linear Undisplaced Fractures

DIAGNOSIS —Local pain is usually experienced on motion or on weight bearing In some instances pain may be referred to *the anterior aspect of the* thigh or knee area The diagnosis is confirmed by antero-

Rim Fractures

DIAGNOSIS —Rim fractures occur most frequently in the posterior quadrant They

may occur in the superior quadrant also but in this area they are usually not a single fracture but are associated with a central or bursting fracture of the acetabu lum Posterior rim fractures may be very difficult to recognize

X RAY EXAMINATION —An anteroposterior view of the hip may indicate very little in posterior quadrant fractures of the acetabulum Stereoscopic views may be helpful but they too may prove inadequate Oblique views of the acetabulum (Figs 377 and 378) taken with the patient face down on the x ray table will show very clearly the extent of subluxation of the femoral head When these views are taken, it is important that the surgeon or an assistant accompany the patient to the x ray depart ment in order to maintain control of the extremity If this is done very little pain will be experienced by the patient.

TREATMENT OF POSTERIOR RIM FRACTURES —After closed manipulation of the hip and if the femoral head and acetabular fragments are in satisfactory position, the patient s leg is placed in suspension with 10–15 pounds of traction for a period of approximately 6 weeks It is most important to begin gentle active motion of the hip following suspension As previously

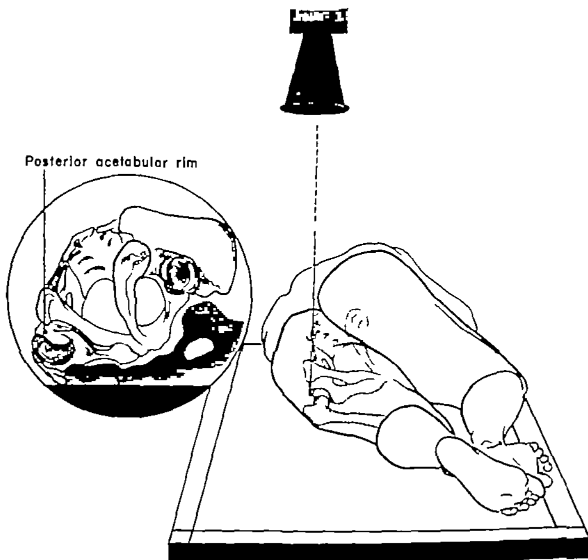


Fig 377 —Technique for x raying posterior acetabular rim. With the patient face down the uninjured hip is elevated 45–60 degrees


A


B


C

tained in reduction, the more favorable the prognosis will be The indications for reduction are

1 Posterior instability of the hip
2 Significant displacement of posterior acetabular fragments
3 Loose bone fragments in the hip joint.
4 *Persistent or increasing signs of sciatic nerve injury or irritation* A careful evaluation of the type of sciatic nerve injury *must be made for the following reasons*

a) The nerve may have received temporary contusion from the initial dislocation and is no longer under pressure This type will show early improvement, and exploration is not indicated.

b) The nerve may be under continuous *or intermittent pressure from a* large displaced posterior acetabular fragment In this instance signs and symptoms of sciatic nerve pressure may persist or become worse and exploration is indicated

c) Irreparable damage or laceration of the nerve from the initial injury may occur The clinical picture is one of complete severance of a portion of the involved nerve with no signs of improvement. Exploration is indicated in order to estimate the degree of damage to repair the nerve sheath and to remove bone fragments from the area.



Fig. 379 —Superior quadrant fracture **Left** multiple small fractures of superior acetabular rim, *incurred when patient fell landing on left hip Treatment consisted of Russell's* traction and later crutches **Center** 1 year later traumatic arthritic changes with disabling pain and limited hip motion **Right** cup arthroplasty

Technique of Open Reduction.—The posterior approach to the hip by splitting the gluteus maximus muscle has proved to be the most direct and effective exposure to the posterior acetabulum and the sciatic nerve (*see pp* 480–485 Surgical Approaches to the Hip) Usually the posterior capsule and the short external rotator muscles are perforated The fractured acetabular fragments will be found at different degrees of displacement within the external rotator muscles or lying free beyond the muscles The sciatic nerve may be palpated *just posterior* and inferior to the acetabulum. The nerve should be identified either superiorly as it dips into the pelvis between the piriformis and the gemellus superior muscles or inferiorly as it courses down the thigh Once the intact nerve is identified it can be followed safely to the area of tissue injury This eliminates pos-

sible damage to the nerve by dissection Specific treatment to the nerve will depend on the degree of injury All posterior acetabular bone fragments are identified The small ones may be discarded but the large fragments must be replaced The femoral head is carefully examined and all evidence of injury noted since allied injuries have prognostic significance The acetabulum is irrigated with normal saline solution The major bone fragments are repositioned to the posterior acetabular rim and secured with one or two metal screws The wound is closed in layers and the patient returned to traction and suspension.

After-Care —Traction and suspension are maintained for a period of approximately 6 weeks followed by partial weight bearing with crutches Full weight bearing should begin in 10–12 weeks and light work within 4–6 months depending on the severity of the injury and the response of the patient to treatment Full activities may be resumed 1 year after injury

TREATMENT OF SUPERIOR RIM FRACTURES (Fig 379) —Many bursting acetabular fractures fortunately leave intact a sizable section of the superior rim which functions as a satisfactory weight-bearing surface In those instances however in which the superior quadrant is comminuted or displaced it is most important to know the extent of the injury Closed manipulation rarely replaces or improves the position of the superior quadrant fragment It is difficult to obtain complete information from x ray examination Anteroposterior or oblique views and stereoscopic views usually do not demonstrate the actual degree of acetabular damage When the surgeon is in doubt open reduction is indicated As a rule more damage and displacement of fragments has been found at operation than appeared on roentgenograms. In cases in which early open reduction and accurate replacement of the articular fragments have been carried out good to excellent results have been obtained When the superior quadrant is not reduced or when it has been injured beyond repair poor results may be anticipated

Technique of Open Reduction —The anterior Smith Petersen approach gives satisfactory exposure of the superior quadrant fractures A lateral hip exposure also gives satisfactory exposure when the fragments extend somewhat posteriorly The displaced fragments are identified Possible injury to the femoral head is noted and the joint examined for loose fragments of bone and cartilage Small fragments are discarded but large ones are reduced and secured with metal screws

After-Care —A longer period of traction and non weight bearing is required for fractures of the superior quadrant than for posterior or central fractures of the acetabulum The extremity should be in traction for at least 8–10 weeks followed by exercises for several months Guarded partial weight bearing with crutches may be started by the eighth or tenth week and may be continued for from 6 months to a year

Central Acetabular Fractures

MECHANISM OF INJURY —This is shown in Figure 376

DIAGNOSIS —The injured extremity is usually shortened and shows slight internal rotation although the position of the extremity will depend on the position of the displaced femoral head Motions of the hip are painful somewhat fixed and resistant to restoration of normal alignment Sciatic nerve pain is rarely present.

Anteroposterior roentgenograms will demonstrate the degree of intrapelvic protrusion and the extent of acetabular fractures

TREATMENT —In most instances in which there is a central fracture of the acetabulum with intrapelvic dislocation or protrusion immediate manipulation of the hip (under anesthesia) is usually performed successfully by the application of manual traction in lateral and longitudinal directions Figures 380 and 381 show examples of central bursting acetabular frac

Fig 380 —A central acetabular fracture with intrapelvic protrusion of left hip injured in automobile accident B immediate manipulation reduction of hip C postoperative traction and suspension D follow up 2 years later excellent function



Fig 381 —Left bursting fracture of left acetabulum with intrapelvic protrusion treated with lateral traction through the trochanter and axial traction through the femoral condyles. Right end result 1 year later excellent function.

tures with intrapelvic dislocation in which initial manipulation was performed by lateral and longitudinal manual traction with reduction of dislocation and fractures doing this is to insert a Kirschner wire through the femoral condyle and to maintain 25–30 pounds of traction for a week or 10 days followed by 10–15 pounds of



Fig 382.—Left bursting superior rim fracture the result of a fall from a height. Right reconstruction of the superior weight-bearing surface by open reduction. At 1 year function of hip was very good



Fig 383 —Central bursting fracture of the acetabulum with preservation of a good weight bearing area in the superior acetabular quadrant Injury received in a quarry accident No specific treatment to right hip because of other injuries patient in bed 8 weeks Excellent function of right hip 2 years after injury

After reduction, x ray films should be taken to determine the completeness of the reduction and the condition of the femoral head and the superior acetabular quadrant If the superior quadrant is intact the extremity can be treated with suspension and skeletal traction A very effective means of traction. Lateral traction may be applied by means of a Kirschner wire placed vertically through the trochanter

If reduction is not obtained by closed manipulation and traction open reduction is indicated (Fig 382) However Figure 383 illustrates a central dislocation of the

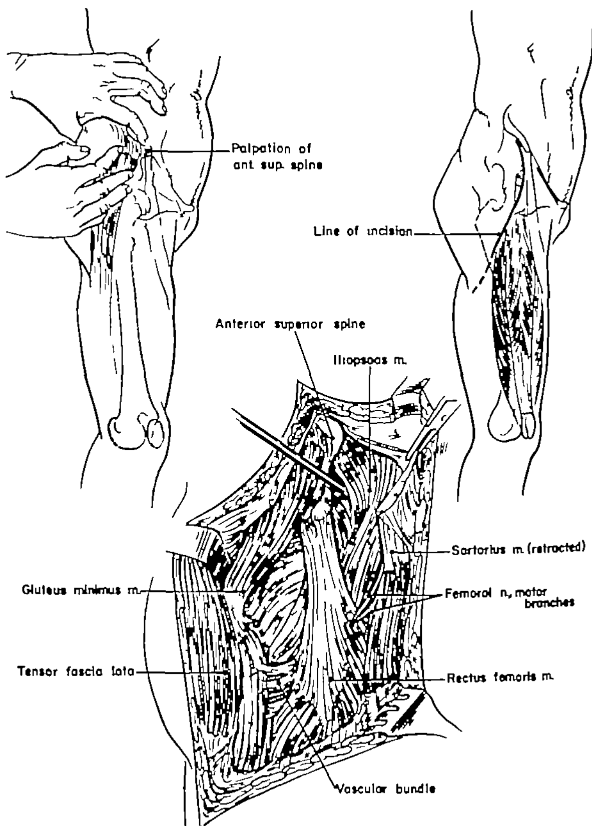


Fig. 385.—Technique of anterior approach to the hip

tality rate of hip injuries due to vascular complications was 0 9 per cent.

ASSOCIATED FRACTURES OTHER THAN THE HIP —Fractures of the femoral shaft associated with dislocation of the hip occurred in 5 instances (4 6 per cent) and patella fractures in 6 instances (5 6 per cent)

SURGICAL APPROACHES TO THE HIP

TECHNIQUE OF ANTERIOR APPROACH

A small sandbag or rolled towel is placed under the margin of the sacrum so that the injured hip is raised In this position the surgeon can easily palpate the anterosuperior spine and the interval between the sartorius muscle and tensor fascia lata (Fig. 385) The incision is started on the crest of the ilium at about the tubercle of the tensor fascia femoris and is carried down across the anterosuperior spine and distally and laterally along the anterior margin of the tensor out to the iliotibial band The lower end of the incision ends just below a line horizontal to the symphysis pubis (Fig 385) Sharp and blunt dissection is carried out in the interval between the sartorius and tensor The tip of the tensor is then removed subperiosteally from the lateral margin of the crest of the ilium and brought down to and along the interval between the anterior and inferior spines of the iliac bone The originating points of the sartorius and Poupart s ligament are reflected subperiosteally from the medial margin of the pelvis down to the anteroinferior spine of the iliac bone This allows retraction of the sartorius muscle and Poupart s ligament medially and of the tensor laterally to expose the underlying straight and reflected heads of the rectus femoris muscle (Fig 385) The anterior circumflex iliac vessels between the vastus externus and the tensor are then identified and ligated in the fascial sheath on the lateral margin of the vastus externus. The fascial compartment in this area is then split down to the vastus externus The dissection is carried up along the anterior margin of the gluteus minimus tendon to the superior neck of the hip and toward the acetabulum This allows exposure of the anterior capsule in its superior and lateral portions (Fig 386) The medial side of the incision then is enlarged in the interval between the iliacus and capsular origin of the iliopsoas The anterior acetabulum is then exposed to the inferior neck and the dissection is carried bluntly and deeply to the lesser trochanter With these two margins exposed medially and laterally sharp dissection may then be made into the capsule and synovia and through the straight and reflected heads of the rectus from the anteroinferior spine across the superior neck out to the greater trochanter The tip of the rectus and the anterior capsule now can be turned down distally in one piece This exposes the anterior acetabulum and the anterior margin of the head and neck out to the greater trochanter A tenotomy of the gluteus minimus tendon will facilitate greater exposure of the superior margin of the neck and allow more room superiorly The head and neck then can be easily dislocated for any type of acetabular or neck surgery

If more exposure of the posterior neck is necessary such as in replacement prosthesis complete capsulotomy is possible inferiorly and posteriorly The base of the neck can be protruded into the wound by extending the thigh over the margin of the table laterally In this position the application of pressure to the sole of the foot directly in line toward the anterosuperior spine with the knee extended will dislocate the hip anteriorly Then by releasing the structures posteriorly it is a relatively simple mechanical job to replace a femoral head or do a femoral head prosthesis in this position.

Modifications of this technique which use only the interval between the tensor and the rectus for nailing are adequate in most instances Such modifications constitute only the lateral portion of the incision without release of the structures from the crest of the ilium By release of these muscles however it is possible to get closer to

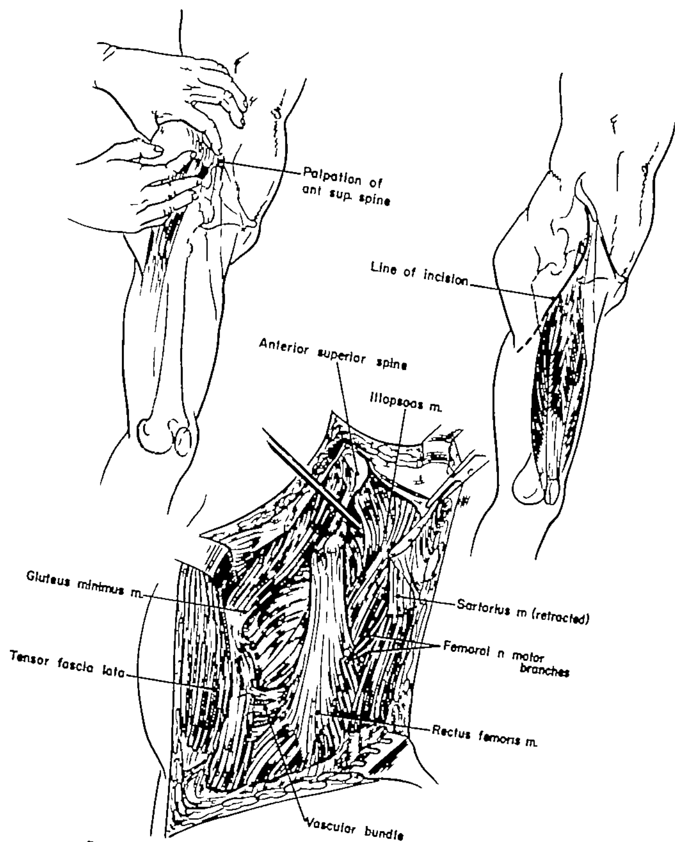


Fig 385 —Technique of anterior approach to the hip

exposure the head of the femur can be removed and a replacement prosthesis in serted For more extensive surgical procedures on the hip it will be necessary to detach completely the gluteus medius from the greater trochanter thus exposing the anterior lateral and posterior aspects of the hip

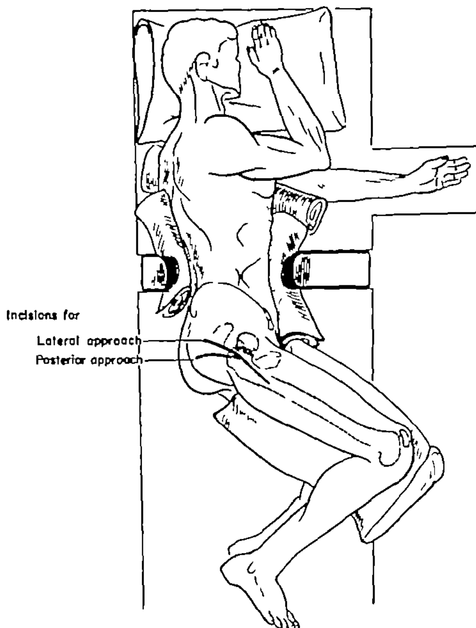


Fig 387 —Illustrating the position of the patient and also the incisions for the lateral and posterior approaches to the hip

Technique of Posterior Approach

This approach is used primarily for ex posure of the posterior acetabulum and the sciatic nerve The patient is positioned as for the lateral approach with the in jured hip upward The incision begins at a point midway between the posterior superior spine and the trochanter It is angled forward and then distally over the greater trochanter and down the shaft for 4–6 inches

The tensor fascia femoris is divided longitudinally and retracted anteriorly The belly of the gluteus maximus muscle is ex posed The gluteus maximus is divided in line of its fibers exposing the external ro-

the anterior acetabulum without undue retraction.

The surgeon should modify the incision into a joint according to the particular needs of the individual case Such adaptation requires a detailed study of the anatomy and an understanding of what really needs to be exposed before beginning the procedure More details of these surgical exposures may be obtained from any standard textbook on orthopaedic surgery and specific details from Campbell s *Operative Orthopedics*

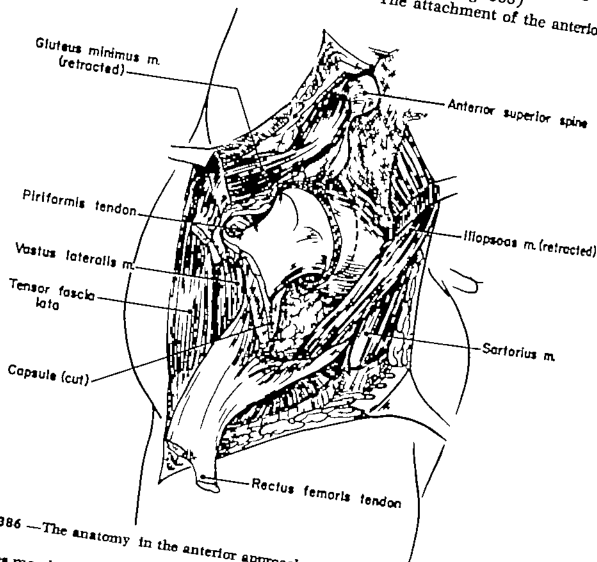


Fig 386 —The anatomy in the anterior approach allows complete exposure of the hip

Technique of Lateral Approach

The patient is turned on his side with the injured hip upward and is maintained in this position by rolled blankets placed anteriorly and posteriorly and fixed kidney rests (Fig 387) The incision gins above and posterior to the gre trochanter and extends distally over trochanter and down along the shaf 4–6 inches The tensor fascia femor divided longitudinally exposing the gre trochanter (Fig 388)

The attachment of the anterior caps along the intertrochanteric line is exposed by reflecting posteriorly the gluteus minimus attachment and a portion of the gluteus medius attachment.

In fresh fractures of the femoral neck it is not necessary to detach the entire gluteus medius rather the extremity is externally rotated and the capsule is opened by a ⊥-shaped incision and extended to the acetabular rim (Fig 389) Through this

tators of the hip Care should be exercised to identify the sciatic nerve as it leaves the pelvis between the piriformis and gemellus superior (Fig 390) To expose the pos terior capsule the external rotators (ge-

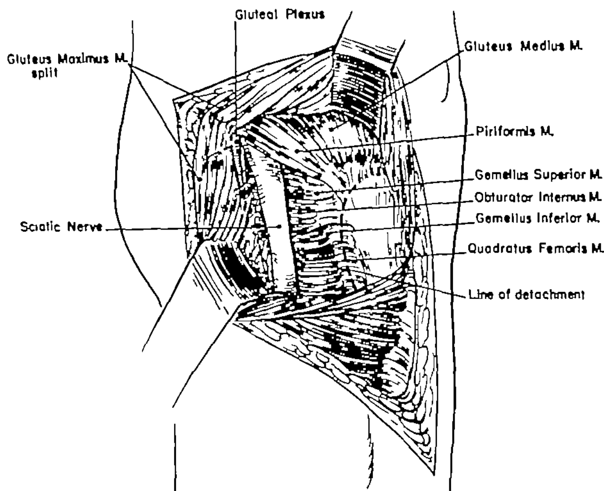


Fig 390 —Posterior approach to the hip for exposing the external rotators of the hip and the sciatic nerve the gluteus maximus muscle is separated in line of its fibers The posterior hip joint and acetabular rim can be exposed by detaching the external rotators

mullus superior obturator internus gemul lus inferior and obturator externus) are divided from their insertions to the greater trochanter The capsule is then opened in a T-shaped manner and the joint examined

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lted detachment of the gluteus minimus and medius muscles that is necessary to expose the capsule

← Fig 389 (bottom) —Technique for presenting the intertrochanteric line the hip is externally rotated and flexed and the capsule is opened to expose the femoral neck and head More exten sive exposure can be obtained by completely separating the gluteus medius muscle from the greater trochanter

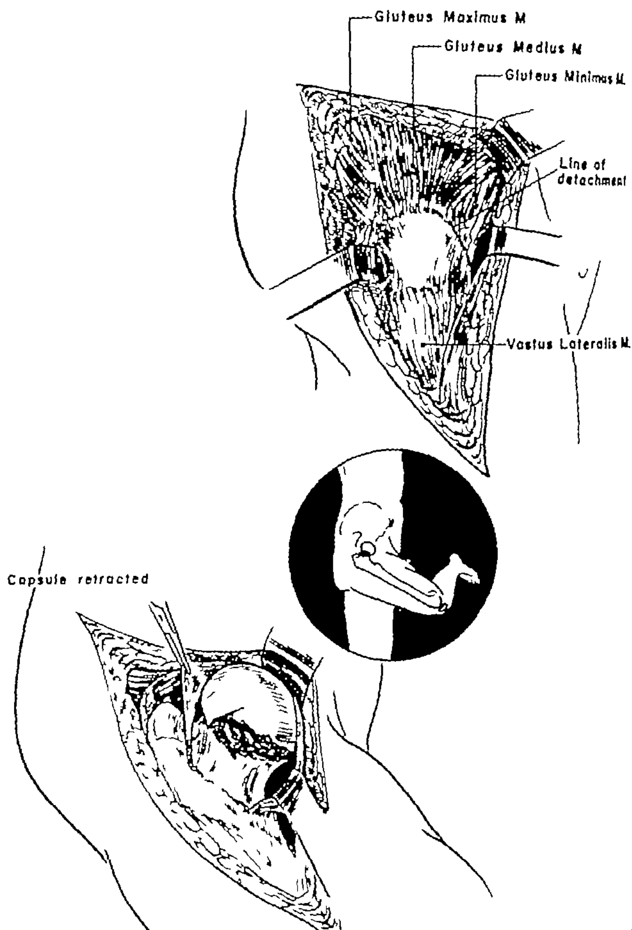


Fig 388 (top) —Lateral exposure of hip the tensor *fascia femoris* divided longitudinally and retracted exposing the attachments to the greater trochanter The dotted line indicates the lim-

26 

Fractures of the Femoral Shaft

FRACTURES OF THE SHAFT of the femur are relatively common and they are serious injuries. Prolonged morbidity and severe permanent disability have often followed these injuries However with proper treatment it should now be possible to obtain excellent functional results after a relatively short period of disability

MECHANISM OF INJURY

Although femoral shaft fractures may result from muscle pull or excessive use as in fatigue stress usually they result from major violence Common causes are severe torsional stresses automobile accidents falls from a height and crushing violence Therefore at the initial examination it is important to search for other injuries which may require emergency treatment and not to allow one s attention to become focused exclusively on the femoral shaft fracture Intra abdominal and genitourinary tract injuries may present surgical emergencies the treatment of which takes precedence over the definitive treatment of the femur In rare instances the hip may be dislocated in association with a fracture of the femoral shaft and the condition may not be recognized

In children these fractures are usually transverse or oblique whereas in adults they tend to be comminuted With oblique fractures especially in adults in one of the fragments there often is an additional crack, approximately at right angles to the main fracture line This crack may be complete producing a "butterfly" fragment (Fig 391) or partial—and even invisible by x ray examination. A crack of this type tends to make the fracture unstable and is of some importance if open reduction is undertaken.

Shattering fractures (Fig 392) are accompanied by very extensive soft tissue damage They are therefore prone to heal slowly because of impaired blood supply to the fracture site Furthermore extensive new bone formation is necessary to restore adequate strength Refractures occur most commonly after comminuted fractures

ANATOMICAL CONSIDERATIONS

Certain anatomical considerations influence treatment and are worthy of review

The femur is the largest bone in the body and it is subject to stresses of considerable magnitude not only during weight bearing but also during simple active move

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The femur is the largest bone in the body and it is subject to stresses of considerable magnitude not only during weight bearing but also during simple active move

ments of the leg even in bed The dense cortical bone of the shaft is slow to heal, requiring many months for remodeling and for the restoration of normal strength.

More or less injury to the soft tissues invariably accompanies a femoral fracture The four branches of the profunda femoris which course around the posterior and lateral aspects of the femoral shaft are particularly vulnerable Extensive hemorrhage into the soft parts of the thigh is therefore common. The femoral artery itself is occasionally ruptured in association with the fracture (Fig 393)

The nutrient artery or arteries leading to the femoral shaft which arise from one or more branches of the four perforating vessels enter the bone along the linea aspera In order to disturb this blood supply as little as possible during open reduction it would seem advisable to leave this are intact when exposing the fracture sit However the preservation of soft-tissue a tachments here may not be feasible if th fracture proves difficult to mobilize and r duce Moreover if an intramedullary na is to be used for fixation, the intramedu lary branches of these vessels will l largely destroyed anyway The work of Trueta and Cavadias on rabbits suggests that an intramedullary nail has a profound effect on the circulation of the bony cortex but that this does not appear to influence fracture healing significantly

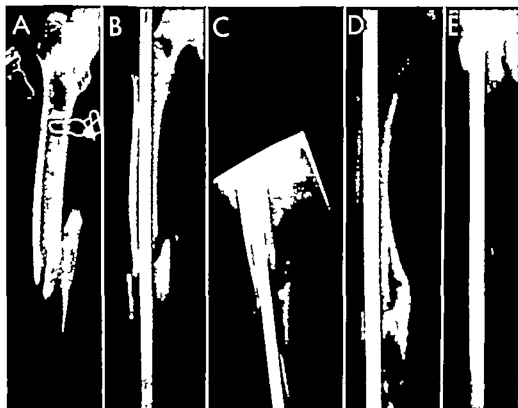


Fig. 391 —Fracture of midshaft of femur A, "butterfly" fragment not visible in initial film. B and C inadequate reduction by open operation and medullary nail, showing displacement of "butterfly" fragment and some shortening Additional fixation with two Parham bands would have been preferable D and E, 1 year after fracture showing that the fracture is healing slowly

The muscles and fascial layers enveloping the femur serve as "tension braces reducing the bending stresses on the femoral shaft. This is a point of some importance in fracture treatment for the thigh muscles that have atrophied as a result of

the prolonged immobilization necessary for fracture healing do not contribute their normal support to the femoral shaft when weight bearing is resumed Efforts to re store normal muscle tone and power are therefore essential not only for function of the extremity but also for actual support of the healing fracture Of particular im

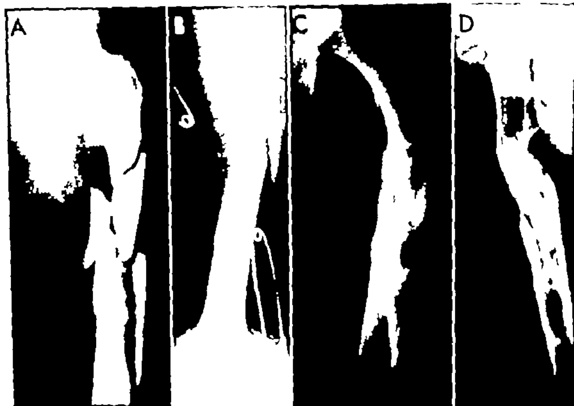


Fig 392.—Anteroposterior (A) and lateral (B) views of severely comminuted fracture of fem- oral shaft treated successfully by traction and a spica. C and D 1 year after fracture almost complete restitution of cortex and medullary canal normal function. Coxa vara and 1 inch shortening although undesirable are small prices to pay in view of the severity of the injuries

portance from the functional viewpoint, is the extensor mechanism For the knee joint to maintain its full range of active flexion and extension the quadriceps must have a high degree of mobility without fibrosis contracture or adhesions Unfor tunately the massive hemorrhage into this muscle and the periosteal stripping asso- ciated with the fracture combined with the prolonged immobilization often required for healing make it difficult to maintain an elastic freely mobile extensor mecha nism

Furthermore prolonged disuse of the knee may result in adhesions involving the joint and periarticular structures with fix ation of the patella and loss of motion of the knee joint. Many months of physical therapy may be required for the restoration of a satisfactory range of motion With de- layed union especially in the presence of sepsis adequate motion may never be re- stored

The arrangement of the muscles of the hip and thigh combined with their great strength may cause rather marked angu lation and displacement of the bone frag ments. The gluteus medius and minimus muscles combined with the iliopsoas and short rotators of the hip tend to flex ab- duct and externally rotate the proximal fragment particularly in fractures of the proximal third of the shaft. The distal frag ment tends to displace medially under the

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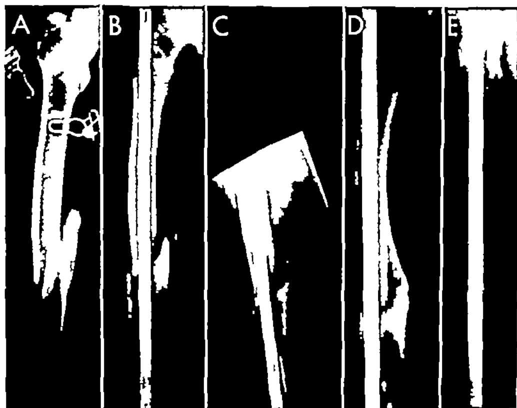


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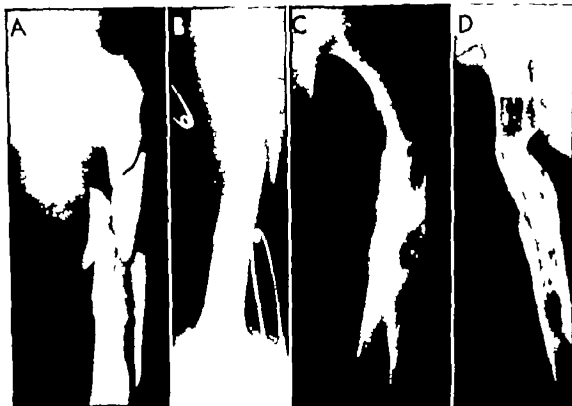


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influence of the adductor and gracilis muscles as well as moving proximally because of the pull of the long muscles arising from the ilium and ischial tuberosity notably the hamstrings posteriorly and the rectus femoris tensor fascia lata, and sartorius anteriorly When fractures in the proximal *shaft are treated by traction the position* of the distal fragment must be adjusted so *that this fragment is* properly aligned with the proximal fragment. It is of course im possible to control the latter As a rule the leg must be supported in a position of flexion abduction and external rotation

Access to the femoral shaft during open reduction is relatively simple to obtain it can be accomplished with little damage to the thigh muscles if the appropriate exposure is selected Either the anterolateral incision of Henry or a posterolateral incision is entirely satisfactory The former is relatively bloodless since it traverses the interval between the rectus femoris and vastus lateralis muscles and splits the vastus intermedius in the direction of its fibers The anterolateral incision serves well for the exposure of fractures of the distal *shaft but the neurovascular bundle* to the vastus lateralis traverses this interval proximally and renders this incision unsuitable for the approach to fractures in the proximal third of the shaft The posterolateral incision, reflecting the vastus lateralis anteriorly from the lateral intermuscular septum provides adequate exposure for the whole shaft with minimal damage to the



Fig 393 —Vascular injury with fracture of the femur **Left** femoral fracture which occurred when thigh was crushed between a piece of machinery and a wall. Patient complained of numbness in leg and foot, but dorsalis pedis and posterior tibial pulsations were present. Initial treatment open reduction and internal fixation with Küntscher nail On the following day increasing evidence of circulatory embarrassment required exploration of femoral artery and a 2½ inch thrombosed segment was excised and replaced by a graft from the corresponding femoral vein **Right** arteriogram 3 months after operation End-result 17 months after injury revealed good pulsations slight loss of knee and foot motions and bone union of fracture.

muscles However the perforating branches of the profunda femoris artery penetrate the intermuscular septum crossing the depths of the wound Troublesome bleed ing may result if these branches are not identified, clamped and ligated

The direct lateral muscle-splitting in cision is seldom warranted since unneces sary damage to the vastus lateralis muscle may result in scarring and loss of knee motion

SYMPTOMS AND SIGNS

In disruption of the continuity of the femoral shaft the diagnosis is quite obvious Deformity—usually anterior and lateral angulation—is visible Shortening abnormal rotation of the extremity inabil ity to move the hip and knee and severe pain complete the picture Crepitus may be felt as the extremity is moved, but ef forts should not be made to elicit this sign. Massive swelling of the thigh may develop with surprising rapidity owing to hemor rhage The signs and symptoms of incipient or overt shock are to be expected The dor salis pedis and posterior tibial pulses must always be checked to rule out the possibil ity of rupture of the femoral artery (Fig 393)

TREATMENT

FIRST AID

Further injury to soft parts and shock can in large measure be prevented by proper first aid measures The importance of this phase of treatment cannot be over emphasized

The essential steps are of course gentle handling and efficient immobilization of the fracture so that the patient can be transported with the minimum of pain The Keller Blake or Thomas splints if avail able are certainly the best means of im- mobilization (Fig 394) However they are not essential With ingenuity a satisfactory splint can be improvised from poles or long boards which are suitably padded and fastened by means of bandages or strips of cloth—one board medial the other on the lateral aspect of the leg and trunk, extending from the axilla to the foot (Fig 395) If nothing else is available the other leg will serve as a useful splint (Fig 396) By securing the injured extremity to the other leg with encircling bandages or strips of cloth preferably with some form of pad ding (e g a folded blanket or clothing) between the legs quite effective immobi lization can be achieved. Bandaging the feet together will control rotation.

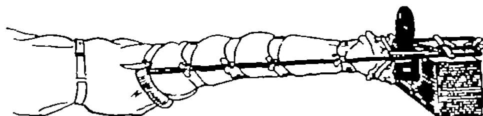


Fig. 394 —Keller Blake splint for first-aid immobilization for a fractured femur The ankle is carefully padded, and the leg is supported in the splint by encircling strips of cloth The shoes and clothing are not removed in order to avoid unnecessary painful movement of the damaged extremity Traction is maintained by means of a strip of cloth which is secured around the ankle, tied over the end of the splint and twisted taut by means of a stick The distal end of the splint is supported to give some elevation

No attempt should be made to remove the patient s shoes or clothing since this will result in unnecessary painful manipu lation. If feasible some form of pressure dressing should be applied to the leg after immobilization because this may minimize blood loss into the soft tissues of the thigh In the case of an open fracture after it is splinted enough clothing should be cut or torn away to permit the application of a sterile or at least a clean dressing, fol lowed by a pressure bandage to minimize

blood loss Elevation of the lower extremities will also combat hemorrhage and shock

Morphine or an equivalent analgesic should be administered and the patient kept warm In open fractures a broad-spectrum antibiotic and tetanus toxoid or antitoxin, as indicated should also be administered as soon as possible

Definitive Treatment

The method of treatment depends on :h factors as (1) the age of the patient) the condition of the skin and soft ts (3) the degree of comminution (4)

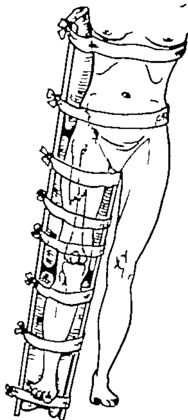


Fig. 395 —Improvised splint using boards or sticks for fracture of the femoral shaft. The lateral splint extends distally from just below the axilla and is secured to the trunk the medial one extends distally from the groin All splints are padded to avoid pressure over bony prominences

the facilities available and (5) the training and preference of the surgeon

In the child delayed union or nonunion is rare and loss of joint mobility seldom results even from prolonged immobilization. Furthermore in the growing child,

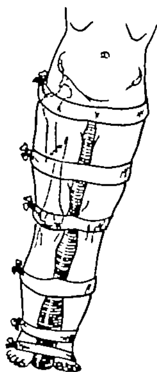


Fig 396 —Improvised immobilization for fracture of femoral shaft where no splints are available Legs with padding between are secured together Feet are also bound together in order to control rotation

open reduction has the additional risk of damage to an epiphysial plate Finally as emphasized by Blount end to-end anatomical reduction may not always be desirable in the child since owing to overgrowth of the injured extremity after fracture permanent inequality of leg length may occur (Fig 397) Although at the Massachusetts General Hospital Fracture Clinic overriding has not occurred in any significant degree it is well to remember that in the young child particularly over riding of ½ inch with good alignment need not cause concern and may even be preferable to perfect end to-end apposition For these reasons open reduction is contraindicated in the treatment of femoral shaft fractures in children

In the aged on the other hand recumbency prolonged pain and immobilization of joints may wreak great havoc Rigid

fixation of the fracture permitting early motion of joints particularly of the knee and freedom of movement without pain is most desirable Pneumonia bedsores joint stiffness and all the other problems that beset this age group may thus be avoided

In the vigorous adult both operative and conservative methods of treatment have their place depending on the circum stances In general if conditions are favor able open reduction and fixation with an tion of the fracture surfaces due to over pull is allowed to occur or if there is soft tissue interposition

Fixation with single or dual plates is sel dom if ever indicated for fractures of the femoral shaft Although such fixation may give sufficient strength to permit early ac tive knee motion and walking with crutches nonunion results too frequently to justify the use of this method In order to apply a single plate or dual plates of adequate



Fig 397 —Anteroposterior (A) and lateral (B) views of spiral fracture of midshaft of femur with a "butterfly" fragment, the result of a football injury sustained by a boy aged 6 Treat ment consisted of 3½ weeks in Russell traction plus 5 weeks in a plaster spica. C and D teleo-roentgenogram 1 year after injury; solid union with slight anterior angulation and ⅛-inch overgrowth function of extremity normal.

intramedullary nail give the best results After adequate intramedullary fixation hospitalization becomes a matter of 2–3 weeks instead of as many months. Ambu lation with crutches is possible early and the white-collar worker can return to work with crutches at an early date

Although under most circumstances traction must still be considered the safest way of treating femoral shaft fractures it should be borne in mind that transverse and short oblique fractures so treated may develop delayed union or even nonunion in adults This is particularly true if distrac length both fragments of the femur must be exposed for a considerable distance re-sulting in impairment of blood supply and a tendency toward delayed union or non-union. Furthermore in the event of sepsis plates are poorly tolerated whereas with an intramedullary nail, union will usually take place even in the presence of drain age (Fig. 398)

Although successful results have been reported with single plates and dual slotted plates there are many reports which em phasize the complications that may follow this method of fixation Experience with



Fig 398 —Anteroposterior (A) and lateral (B) views of open fracture of femur received, with other injuries, at time of a fall down an elevator shaft. Initial treatment concerned the "other" injuries the thigh wound was simply debrided and closed and the fracture immobilized by skeletal traction through the tibial tubercle The thigh was well healed 11 days after injury and open reduction and fixation with a Küntscher nail were performed Wound sepsis resulted, and the wound was drained 10 days postoperatively Walking on crutches the patient was discharged 3½ months after injury The wound was still draining but the knee could be flexed 85 degrees Sequestrectomies were performed 8 and 12 months after injury (C and D fracture before first sequestrectomy E and F after last sequestrectomy) Two years after injury the nail was removed (G and H show fracture at this time) the sinus and scar tissue were excised, and the wound closed Several months later at follow-up the wound was found to be closed and the patient had knee motion from full extension to 45-degree flexion he was able to be on crutches much of the time This case illustrates the value of leaving the nail in place until bone union has taken place

plate fixation has also been disappointing in the Fracture Clinic of the Massachusetts General Hospital If open reduction is con sidered it should be undertaken only if rigid fixation with an intramedullary nail is feasible

There are however exceptions to this rule In some proximal or distal shaft frac tures involving the subtrochanteric or su pracondylar regions especially if there is comminution intramedullary fixation may not be feasible If the position secured by traction is not acceptable some other form of internal fixation will be necessary A Jewett nail plate or blade plate long enough so that 4 or more screws can be placed in sound bone may then be indicated.

Manipulative reduction and fixation in a plaster spica may occasionally be feasible in transverse fractures in children if the ends can be locked during manipulation In fractures of the femur occurring in infants during birth this method may be used even if such locking is not achieved be- cause in infants major deformities are cor rected rapidly by growth In adults fixa tion in a spica is seldom if ever justified for it is difficult if not impossible to main- tain satisfactory position of the fragments. Incomplete fractures without displacement may constitute an exception to this state- ment since the use of a spica here will give adequate immobilization and obviate the need for prolonged hospitalization as well as the risk attending operation

TRACTION

Skin Traction

Although there are many satisfactory ways of applying traction to the skin sev eral principles should be emphasized

The patient s skin and subcutaneous tis sues must be healthy and able to tolerate traction Atrophy due to advanced age im paired sensation dermatitis or skin dam age due to injury are contraindications to this form of treatment. If careful question ing reveals that the patient has developed a contact dermatitis from adhesive tape compound benzoin tincture or resin skin adherent in the past, then skin traction should be avoided

Finally if skin traction is used the ex tremity should be examined frequently Should the areas where the straps are ap- plied become tender to palpation skin ir ritation should be suspected and the trac tion straps removed promptly Similarly complaints of persistent itching or burn ing are danger signals which require in- spection of the traction straps Early re- moval of the skin traction under these circumstances may avoid extensive damage to the skin.

The traction straps must be as large as possible in order to keep the tension per unit area of skin at a minimum A good method is to use adhesive straps 2–2½ inches wide which extend along each side of the leg from a point 2–3 inches above the malleoli well up on the thigh Oblique or transverse encircling adhesive straps are not advised If the edges of the straps are too taut ¼ and ½ inch oblique cuts made with scissors at 1 to 2 inch intervals along each edge will give a smooth fit (Fig 399 C) An encircling elastic band age will hold the tape in place (Fig 399 *D*)

In general not more than 10 pounds of pull should be applied by skin traction. Ex cessive weight and uneven tension are common causes of skin breakdown

Excessive pressure on the malleoli may cause skin necrosis Several turns of sheet wadding 2 inches in width and placed just proximal to these bony prominences will avoid this

If the traction straps show evidence of slipping all encircling bandages should be removed and the region of the ankle and dorsum of the foot inspected Constriction and skin necrosis will thus be avoided. Us ually the traction straps need not be dis turbed and all that is needed is to reapply the bandage in a more proximal position However new skin adherent and traction straps may be necessary

Pressure or tension in the region of the fibular head may cause peroneal palsy The

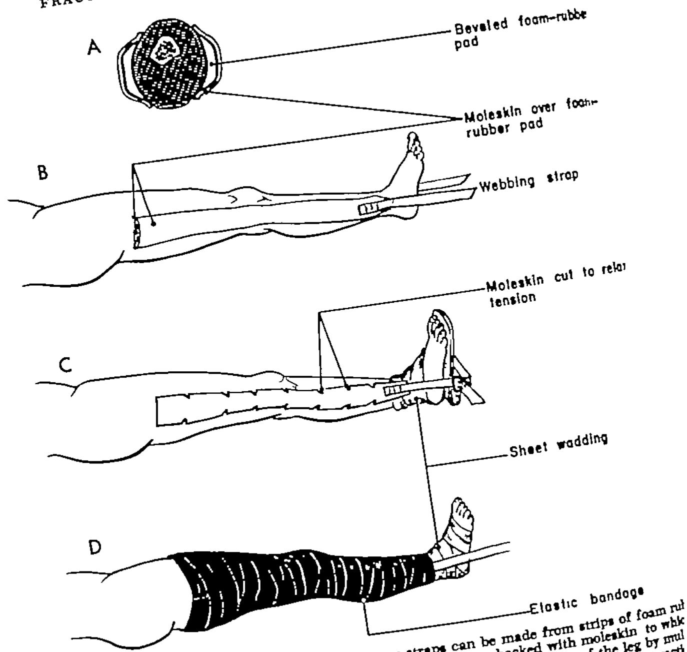


Fig 399 —Types of traction straps Temporary straps can be made from strips of foam rub ber ¼ inch thick The edges are beveled (A) and the strips are backed with moleskin to whic are stapled webbing straps (B) Such straps can be made to fit the contours of the leg by mul ple cuts as illustrated in C. Elastic bandages (D) applied from the toes to the top of the tracti straps, can be used to maintain the contact of the traction straps with the skin

common causes of foot drop due to the use of traction in the treatment of fractures of the lower extremity are tight bandages or traction straps a narrow and inadequately padded sling with Russell's traction or pressure from the splint used for suspension especially if the leg lies in external rotation

lternative method of applying traction is to use straps fashioned from strips of ¼ inch foam rubber backed with moleskin (Fig 399) These straps are held snugly against the extremity with elastic bandages This method is of value as a temporary measure but is not advised for definitive treatment because the straps tend to slip gradually requiring reapplication in 24–48 hours

Skeletal Traction

This method is indicated where the condition of the skin is such that skin traction will not be tolerated where heavy traction is necessary to correct over riding or to combat powerful muscles and usually where prolonged traction (of 6–8 weeks or more) is anticipated

A threaded Kirschner wire should be used It is easy to insert and produces a relatively small tract through the soft tissues and the bone Unless a threaded wire is used the wire may become loose and slide Such movement can cause contamination leading to soft tissue sepsis and even to osteomyelitis with the formation of a ring sequestrum Furthermore the Kirschner wire because of its small caliber may cut through porotic or cancellous bone

Ordinarily three points in the lower extremity are used for skeletal traction—the tibial tubercle the supracondylar region of the femur and the os calcis (Fig. 400)

The tibial tubercle is the safest and most

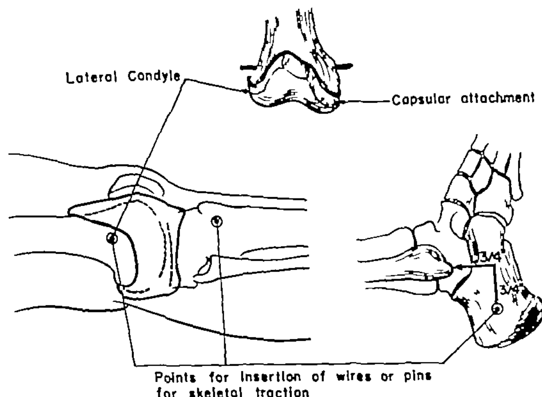


Fig 400 —Sites for insertion of Kirschner wire for skeletal traction In the tibial tubercle (top) the pin should be inserted one finger s breadth posterior to the prominence of the tubercle By starting on the lateral side accidental injury to the peroneal nerve can be avoided by careful placement of the wire If a wire is inserted in the opposite direction, it may deviate during its course through the bone and damage the nerve. In the supracondylar region of the femur (left) the pin or wire is inserted as far posteriorly and as far distally as possible in order not to transfix the quadriceps mechanism and to avoid the synovial expansions of the knee joint. Great care is needed to avoid entering the knee joint with the wire It is inserted just proximal to the most proximal palpable prominence of the lateral femoral condyle and carefully directed at a right angle to the femoral shaft and in the frontal plane with the leg in neutral position The wire will then emerge through the medial femoral condyle In growing children the point of insertion should be slightly more proximal in order to avoid injury to the epiphysial plate In the os calcis (right) the wire is started on the lateral side at a point approximately ¾ inch behind and ¾ inch below the tip of the lateral malleolus or at the midpoint of a line drawn between the tip of the lateral malleolus and the tip of the heel (Adapted from Scuderi C S *Atlas of Orthopedic Traction Procedures* [St. Louis C V Mosby Company 1954])

satisfactory site Here the bone is dense there are few soft tissues to be traversed and sepsis or cutting-out of the wire should it occur does not cause serious complications. The only disadvantage to the use of this site is the fact that, if heavy traction is necessary for a considerable period particularly with the knee in flexion stretching of the ligaments of the knee may occur with resultant instability

The supracondylar region is used if heavy traction is indicated or if extreme flexion of the knee is necessary as for example with the so-called "90-90-90" traction. The chief objections to this location for skeletal traction are the risk of damage to the epiphysial plate in children the danger of sepsis along the pin tract with scarring down of the quadriceps and the possible contamination of the knee joint should the wire cut through the cancellous bone after prolonged traction and enter the joint.

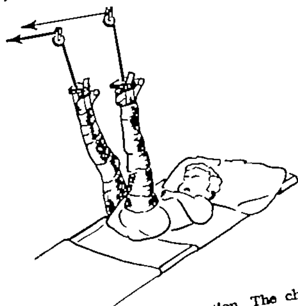


Fig 401 —Bryant's traction. The child is placed on a Bradford frame and the traction is adjusted so that the buttocks are raised from the frame By putting both legs in traction rotatory movements of the pelvis are prevented However some surgeons prefer to put only the involved leg in traction maintaining that more traction can be achieved in this way Warning Circulatory complications may occur with this treatment (See text.)

In fresh fractures of the distal shaft the fracture hematoma may extend distally in which case a supracondylar pin tract will communicate with the hematoma. Severe infections have resulted from this condition, endangering both the life and the limb of the patient. Hence for distal shaft fractures supracondylar skeletal traction is not recommended

The use of the os calcis as a site for skeletal traction in the treatment of femoral fractures is seldom indicated. The wire is likely to cut through this cancellous bone and pin-tract infections at this site are particularly serious leading to resistant chronic osteomyelitis of the os calcis or septic arthritis of the subastragalar joint. However in some situations this may be the only site available

The wire should be inserted under the rigid aseptic conditions of the operating room Although local anesthesia may be used a general anesthetic is preferable for it will permit a manipulative reduction of the fracture at the time that the traction is set up

During the insertion of a Kirschner wire the soft tissues may show a tendency to become wound around the wire as it is being drilled in This may impede or even block the passage of the wire through the bone. This difficulty can be avoided by inserting a large-bore hypodermic needle down to the bone and threading the wire through the needle which can be removed before the spreader is applied An alternate measure, if a threaded wire is not being used, is to oscillate rather than rotate, the wire as it is driven through the bone and soft tissues

The skin and subcutaneous tissues at the points of entrance and exit of the wire should not be under tension once the wire is in place because persistent tension leads to necrosis and sepsis To avoid this difficulty a stab wound should be made with a scalpel at the point of insertion and also over the point of the wire as it tents the skin on the opposite side.

In order to place the wire accurately in the supracondylar region it is well to use a guide if one is available

Four types of traction commonly used are Bryant s traction Russell s traction suspension traction and "90-90-90" traction In general Bryant s traction should be used in infants Russell s in older children and suspension with skeletal traction by a wire through the tibial tubercle in advantageous because it facilitates nursing care

It should be emphasized that Bryant s traction is not without danger Volkmann s ischemic contracture has been reported in both involved and uninvolved legs Great care should be observed in applying the

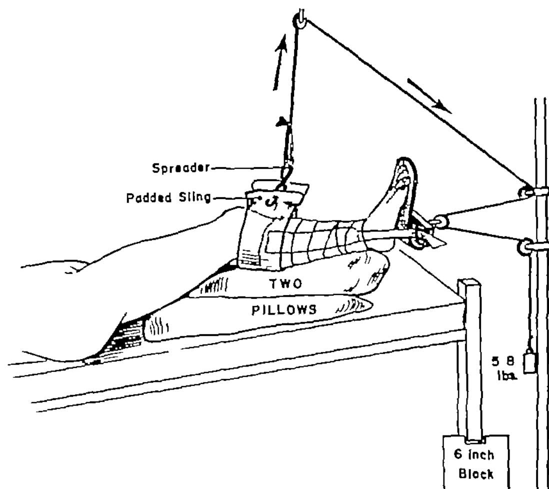


Fig. 402.—Russell s traction The resultant of the vertical and horizontal forces is in line with the long axis of the femur The leg rests on two pillows arranged to give support to the whole extremity particularly the thigh. The sling beneath the knee is wide and well padded. The overhead pulley is placed slightly distal to the knee The lower end of the bed is raised at least 6 inches to provide countertraction.

adults "90-90-90" traction may be preferred when frequent dressings of thigh wounds are necessary

Bryant s Traction —For most children 6 years of age or less Bryant s traction (Fig 401) is satisfactory For large patients in this age group however it is not suitable since they are too tall and heavy and are probably more prone to vascular complications For infants it is particularly traction straps and encircling bandages to be sure that they are not too tight. Careful check on the circulation and the sensation of both feet must be made at frequent intervals after the traction has been applied

Russell s Traction —This form of traction (Fig 402) is simple to apply and is well suited for the treatment of femoral fractures in older children and in some adults It is effective and free from serious

complications except for peroneal palsy A careful vigil to avoid excessive pressure in the region of the common peroneal nerve with resultant foot drop is essential. Special measures to avoid posterior bowing at the fracture site may be necessary also since there is no external support under the thigh An additional sling beneath the thigh with upward traction perpendicular to the long axis of the femur and sufficient to restore its normal anterior bow may be necessary

Russell's traction may also be applied by means of a Kirschner wire through the tibial tubercle (Fig 403) The vertical component of the traction is applied to the bow while the horizontal component is secured to the projecting ends of the wire by means of webbing straps which are buckled to the foot piece This avoids the need for a second wire in the os calcis which is sometimes used The vertical pull on the traction bow affords excellent control of rotation When this type of traction is employed suspension of the leg with a Hodgen splint and a Pearson attachment should be used in preference to pillows.

SUSPENSION TRACTION —Suspension traction is the simplest and most widely used method in adults (Fig 404) The thigh and lower leg are supported on some form of splint preferably a Hodgen splint and a Pearson attachment With appropriate adjustment and the use of a pad behind the thigh the tendency of the fracture to angulate posteriorly due to the pull of gravity can be corrected and the normal anterior bowing of the femur restored. If pulleys with minimal friction are used and the weights are carefully adjusted the extremity can be so counterbalanced that it moves up and down with the patient dur

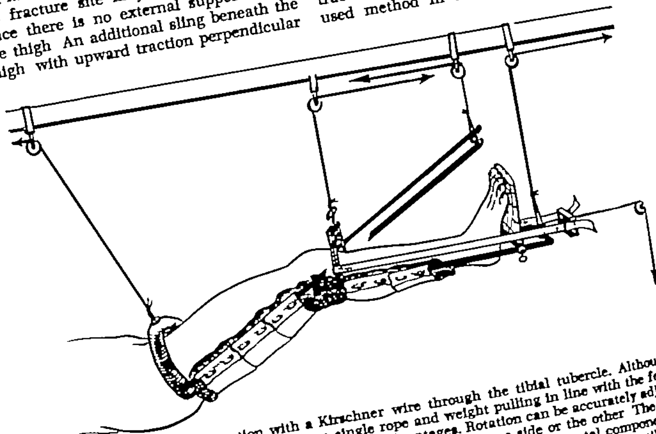


Fig 403 —Russell's traction with a Kirschner wire through the tibial tubercle. Although a comparable pull could be achieved by a single rope and weight pulling in line with the femur this rather more complicated method has some advantages. Rotation can be accurately adjusted and maintained simply by shifting the vertical component to one side or the other The direction of pull can be shifted by increasing or decreasing the vertical or horizontal components as indicated Note that the straps which transmit the horizontal pull to the wire in the tibial tubercle are attached distally to a spreader which is sufficiently wide to permit the Pearson attachment to move between the straps Knee motion may thus be instituted early A threaded Kirschner wire should be used to prevent the wire from sliding in the bone (See Figure 404 for details)

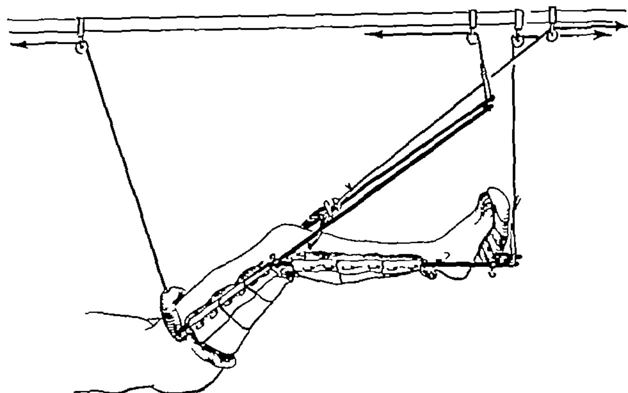


Fig 404 —Suspension traction. The leg is supported on a felt pad which is covered with stockinette and laid on top of webbing slings The slings are secured to the Hodgen splint and Pearson attachment by means of large safety pins The Hodgen splint is supported at both ends by sufficient weight to just balance the weight of the extremity The Pearson attachment is supported by a rope at its distal end, to which sufficient weight is attached to just balance the weight of the leg Traction is applied usually through the tibial tubercle as illustrated With this arrangement for suspension rarely is the pin or wire placed through the supracondylar region. Adjustments are made according to what the roentgenograms of the femur show Anteroposterior angulation is corrected by (1) tightening or loosening the sling beneath the thigh, (2) sliding an additional pad beneath the thigh at the appropriate level if there is persistent posterior angulation or displacement of one of the fragments and (3) flexing or extending the knee thereby relaxing or tightening the gastrocnemius muscle The latter maneuver is of particular value in the case of distally placed fractures Medial or lateral angulation is corrected by changing the direction of pull in such a manner as to align the distal with the proximal fragment Shifting the position of the medial or lateral proximal ends of the Pearson attachment—either proximally or distally on the Hodgen splint as indicated—may also correct angulation The amount of rotation may be estimated by placing the opposite extremity so that the greater trochanters on the two sides are in comparable positions The suspension is then adjusted so as to hold the fractured extremity in a position comparable to that of the normal one This is usually in slight external rotation In general if the supporting ropes for the Hodgen splint pull in a slightly cephalad direction there will be less tendency for the splint to slide off the leg

ing nursing procedures Furthermore some active and passive knee motion is possible by carefully counterbalancing the Pearson attachment

Although some form of skin traction may be used in treating femoral shaft fractures in adults past experience indicates that skin traction is often unsatisfactory Skeletal traction with suspension is recommended

"90-90-90" TRACTION — This form of traction (Fig 405) may be of value in infected open fractures It may facilitate dependent drainage and the performance of daily dressings It may also be used in children where a satisfactory position is not obtained by other methods Here a Kirschner wire is inserted in the supracondylar region and the lower leg is suspended in the horizontal position by means of a plas-

ter boot and slings so as to hold the knee hip and ankle in 90-degree flexion. With this method the hamstrings are relaxed and accurate control of the distal fragment is assured by the wire and the suspended lower leg

The disadvantages of this technique include the need for a supracondylar wire with its attendant dangers and the flexed position of the knee which may be undesirable if prolonged traction is necessary

Closed Reduction

Regardless of the type of traction employed it is advisable at the outset to carry out, under general anesthesia a manipulative reduction combined with traction that is carefully adjusted to maintain the position gained by the manipulation. All too frequently traction is applied and then repeated adjustments are made as films from a portable x ray machine reveal unsatisfactory position. Under these circumstances a good reduction may never be obtained

Duration of Immobilization

In children, callus is formed rapidly and the fracture becomes stabilized in 3-5 weeks At this time good callus will be visible by x ray film It is then possible to apply a plaster spica without fear of losing position and to discharge the patient home. The duration of immobilization in this cast will vary but ordinarily immobilization must be maintained for 8–12 weeks from the time of fracture or until an x-ray film shows that mature callus is present A one and one-half plaster spica, incasing the involved leg down to the toes and the normal leg to just above the knee is applied at first With fractures involving the distal

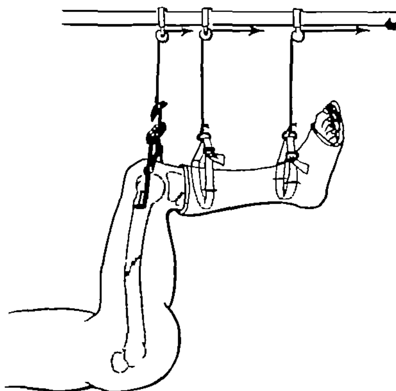


Fig 405 —90-90-90 traction Traction is applied to the femur in a vertical direction by means of a Kirschner wire inserted in the supracondylar region The lower leg is merely suspended, the weights being adjusted to counterbalance the weight of the leg plus that of the plaster boot. With the pull of gravity in the axis of the femoral shaft angulation can be controlled without the use of splints Nursing care is relatively simple and access to the thigh is made easy should daily dressings be required. The webbing straps supporting the cast are incorporated in the plaster

femur the normal leg may occasionally be left free but in general it is advisable to immobilize the pelvis so far as possible by having the cast include the normal hip and thigh During the last 2 or 3 weeks of immobilization in plaster the portion of the cast incasing the normal leg may be removed thus converting it to a single spica

For adults traction must be maintained considerably longer usually for 12–16 weeks During this time great care must be exercised to avoid distraction particularly in transverse midshaft fractures Once alignment has been obtained the weight should be reduced gradually However the reduction in weight must be guided by periodic x rays in order to avoid loss of position.

As soon as the position has become stabilized especially if the bone ends are locked quadriceps and hamstring exercises should be started.

Refracture especially in adults is a serious complication which may result in permanent loss of knee motion Traction should not be discontinued until x rays of good quality show adequate healing Factors that delay healing and the restoration of strength at the fracture site such as severe comminution with separation of the fragments loss of bone substance and infection should be given due consideration when the decision to discontinue traction is made If any of these factors prevail traction may have to be maintained for 16 weeks or longer

In adults immobilization in a plaster spica after a period in traction is rarely either feasible or worth while unless the home situation is such that with such immobilization earlier discharge from the hospital will be possible

A walking spica extending from the nipple line to the toes and with a walking heel may occasionally be of value For instance if the stimulus of weight bearing is desired in the presence of delayed union with a stiff knee such a spica is probably the most effective form of external support However a spica is useless for an obese individual and is of doubtful value for fractures of the proximal shaft As a general rule a walking spica is seldom indicated

Ordinarily guarded weight bearing with crutches is started when good sound callus is shown to be present by x ray film and when the patient has regained 40–60 degrees of knee flexion and good muscular control of the leg as evidenced by the ability to do straight leg raising Full weight bearing should not be permitted until mature healing has occurred which will require approximately 6 months or longer from the time of fracture Restoration of normal bone strength probably does not occur until a year or more has elapsed

Although ischial weight bearing braces are sometimes prescribed as supportive apparatus their use is not recommended. Refractures while walking with these braces on or even during the process of putting them on or taking them off have been reported. It is difficult to see how a brace of this type can be very effective Although such an apparatus may reduce the stress on the fracture which is associated with weight bearing during movements of the leg the weight of the apparatus must increase the bending stress at the fracture site to a considerable degree Furthermore wearing the brace may give a false sense of security Careful instruction of the patient with regard to the dangers of refracture and careful supervision until crutch walking with guarded weight bearing is skillfully and correctly performed is the preferred procedure

A stiff knee which has resulted from prolonged immobilization or other cause tends to increase the leverage on the fracture site particularly if the patient slips or falls in such a manner as to cause knee flexion When there is limited knee motion protection must be prolonged and every *effort* made to improve knee motion by appropriate physical therapy *Too vigorous efforts* to increase motion by passive stretching or progressive resistance exercises may cause refracture Active exercises for both the flexor and the extensor muscles of the knee are the first and most important steps in rehabilitation of the knee *after* a fracture of the femoral shaft. The other meas-

ures must await the restoration of adequate strength at the fracture site

It has been suggested that a hip flexion deformity developing after fracture of the femoral shaft, may predispose to refracture If such a deformity is present crutches should probably be used for a prolonged period

Open Reduction

Ever since the essential value of intramedullary fixation was demonstrated by Küntscher open reduction in properly selected cases has become the unquestioned treatment of choice in the minds of more and more surgeons The high incidence of union the short hospitalization and the early mobilization with maintenance of knee motion attained by this procedure represent a great improvement over other methods However it should be obvious that this method has definite limitations. Special instruments for the insertion cutting and removal of the nail as well as all sizes and lengths of nails must be available A fully equipped operating room and adequate assistance as well as x ray facilities in the operating room, are absolutely essential

It goes without saying that the position of the nail must be established during the procedure Open reduction is not ordinarily suitable for severely comminuted, or shattered, fractures These require much additional fixation in the form of screws Parham bands or circumferential wires and the extensive operative exposure necessary to mobilize and fix these fractures destroys the already damaged blood supply to the shaft predisposing to delayed union or nonunion. Intramedullary fixation is best suited for transverse or short oblique fractures but it can also satisfactorily fix long oblique and moderately comminuted fractures provided that additional fixation is used in conjunction with a large snug fitting nail of adequate length (Fig. 406) In this connection it is of some interest that in many of the patients at the Massachusetts General Hospital Fracture Clinic in whom a single Parham band was used

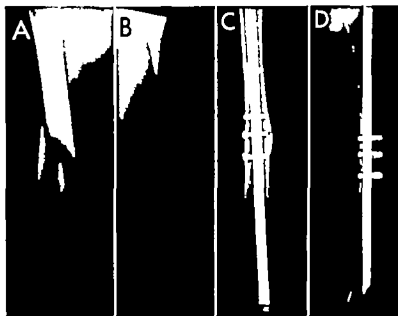


Fig 406 —Anteroposterior (A) and lateral (B) views of a femoral fracture sustained in a fall The extremity had been partially paralyzed as the result of anterior poliomyelitis Open reduction and fixation with a Küntscher nail and 3 Parham bands were performed shortly after admission C and D 1 year after injury fracture healed hip and knee motions normal, and no shortening The use of Parham bands to hold the "butterfly" fragment gave good fixation and a perfect result. (See Fig 391)

around an oblique fracture the band gave way at the coupling with slight resultant shortening (Fig 407) In fractures where circumferential wires or bands are necessary more prolonged protection is warranted If more than one Parham band is used in close proximity to the main fracture line some delay in union may result presumably owing to impairment of the blood supply Parham bands should not be placed too close together or in such a manner that they completely surround a short oblique fracture since they may obstruct the formation of the peripheral callus

The imposing list of complications attending open reduction should be reviewed by anyone considering this method of treatment for the first time Complications can be readily avoided if suitable equipment and technique are used.

No attempt will be made here to describe the operative procedure in detail (see Chapter 32 on Operative Treatment of Fractures) but a few comments may be of interest

The patient should be placed on the uninjured side with the involved leg draped free to permit the necessary manipulations for reduction When the guide rod is inserted retrograde the hip should be flexed *to approximately 90 degrees and adducted* By this expedient the point of exit of the rod through the skin is close to the tip of the trochanter and minimal damage to the gluteal muscles results

Blind nailing is seldom if ever justified Exposure of the fracture site by the posterolateral or anterolateral approaches simplifies the procedure and has the great advantage that the proper diameter of nail can be selected by actual test or the canal enlarged if need be In this way inadequate fixation due to too small a nail or the danger of too large a nail becoming impacted within the canal during insertion can be avoided Furthermore retrograde insertion of the nail or guide rod in the proximal fragment avoids the difficulty sometimes encountered in selecting the proper site for the insertion of the nail in the trochanter during blind nailing Finally exposure of the fracture site is advantageous because cracks or incomplete fractures which were not visible in the x ray film *may be found If these are not secured* by additional fixation displacement of a "butterfly" fragment with shortening and loss of fixation may result (Fig 391)

The nail should be of sufficient length so that its distal end engages the cancellous bone in the subchondral region of the distal femur (Fig 393) and its proximal end extends not more than 1 cm above the greater trochanter With the nail so placed secure fixation can be achieved and a Trendelenburg limp due to a painful bursa about the projecting proximal end of the nail will not develop Although the length of the nail can be determined preoperatively by making a roentgenogram of the uninjured femur this procedure is not necessary For the Hansen and Street nail a sufficiently accurate determination of length can be obtained by subtracting 1 inch from the measured distance between the tip of the trochanter and the knee joint when the hip and knee are flexed

For the Küntscher nail the length can be determined exactly at the time of operation by an x ray film which is taken after the reduction of the fracture and the insertion of the guide rod the estimated correct distance The distance of the point of the guide from the knee joint and the amount of guide rod projecting from the tip of the trochanter enable the surgeon to determine the exact length required.

With the aid of an x ray film the proper diameter of the nail may also be estimated *preoperatively However this estimation is* not necessary if open reduction is carried out for with a full supply of nails and with appropriate drills reamers or broaches in the kit no difficulty should be encountered in obtaining a satisfactory fit of the nail and adequate fixation.

The fracture should be reduced and held by suitable clamps before the nail is driven *into the distal fragment* By so doing a good reduction and stable fixation are assured In a fracture in the middle third of the shaft the normal anterior bow of the

femur should be corrected by angulating the fracture slightly posteriorly as the nail is driven down the medullary canal By this maneuver the tendency for the nail partic ularly the Küntscher type to penetrate the distal anterior cortex can be minimized.

The nail must fit snugly in the narrowest portion of the medullary canal which is just proximal to the midpoint of the shaft mm if this is feasible It is preferable to slightly enlarge the canal with a drill or broach to accommodate this size of nail rather than to use a smaller one With the Hansen and Street nail the same considerations apply but where possible the 11 mm size should be used in preference to the 9-mm one

As the nail is driven along the medullary

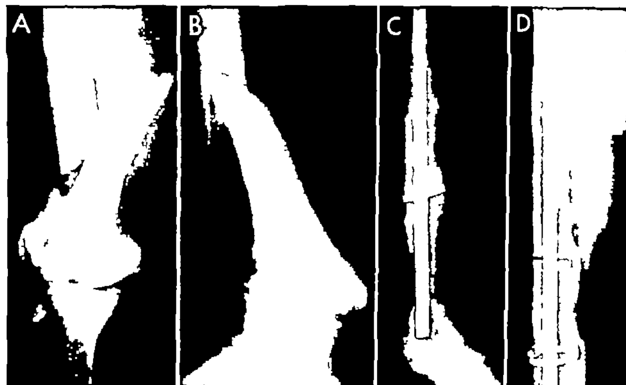


Fig 407 —Lateral (A) and posteroanterior (B) views of pathological fracture of femoral shaft in Paget s disease Open reduction and fixation by means of a Küntscher nail and a Parham band were done after proximal osteotomy which was performed to correct bowing of the shaft and to permit the insertion of the nail. C and D 3 months postoperative healing progressing satisfactorily although the Parham band has pulled loose At follow-up 1 year after the operation there was bone union and good knee and hip function

It may be necessary to enlarge the canal with a drill or broach if the canal is unduly small or obliterated by sclerotic bone as in a nonunion On the other hand if the canal is unduly large as may be true in osteoporosis two Küntscher nails nested one within the other may be necessary to secure a snug fit.

In selecting the size of the nail it should be emphasized that nails of small diameter may break or bend. With the Küntscher nail the minimum diameter should be 10

canal, it should move with comparative ease with each stroke of the mallet If the nail begins to bind the cause for this must be determined before it is driven further and becomes impacted making removal or further insertion difficult or impossible Most frequently such a situation is due to the nail s being too large Less commonly it results from the nail s penetration of the cortex.

On rare occasions as the Küntscher nail is driven over the guide rod it may become

constricted and grip the guide rod so firmly that further insertion or removal is diffi cult. This condition can be avoided by checking the guide rod periodically as the nail is inserted If the nail binds or if the guide rod starts to move with the Küntscher nail, the guide rod should be removed before the nail is driven farther In any event the guide rod is removed when the nail is well past the fracture site

Since the maximum bending stress on the femur during weight bearing tends to cause lateral angulation an intramedullary nail should be placed so that it presents its maximum strength to stresses applied in this frontal plane With the Hansen and Street nail, the long diameter should lie in this plane while with the Küntscher nail the eye should be posterior and lateral and the slot anterior and mesial

With fractures in the proximal shaft or the distal shaft, or where bowing has oc curred owing to Paget s or other bone disease the distal end of the nail will strike the convexity of the curve of the femur making further insertion impossible with out penetrating the cortex. Under these circumstances the femur should be osteotomized at the apex of the curve and straightened. The resulting fragments of the shaft can then be threaded onto the nail, and fixation of the original fracture and of the osteotomy secured (Fig 407)

In some cases bone grafts should be placed around the fracture site before the wound is closed Shavings of cancellous bone obtained from the ilium at the time of operation are preferable for this pur pose As an alternative shavings from the nearby femoral cortex may be used al though these are less effective Such grafts *can probably be omitted in young adults* where union is almost certain to occur

Postoperative Management

Traction should be avoided and efforts made to encourage impaction of the frag ments Simple suspension or support on *pillows may* be used during the immediate postoperative period Muscle setting of the quadriceps hamstrings and gluteal muscles should be started by the second or third day

Occasionally after insertion of the med ullary nail rotation at the fracture site may still be possible although this should not happen if the nail is of sufficient length and fits snugly within the canal Should this situation arise suspension with the knee flexed or a plaster boot with an outrigger to prevent rotation may be used until heal ing has progressed sufficiently to prevent rotatory displacement

Guarded weight bearing with crutches is ordinarily commenced as soon as the wound is healed Non-weight bearing with the leg dangling is contraindicated since this may cause distraction with resultant delayed or even nonunion. Partial weight bearing is instituted from the start and continued until mature callus is visible by x rays or for 4–6 months as a rule For full weight bearing it is safer to allow bone healing to progress to an advanced degree In the absence of solid bone union fracture or bending of the nail may occur owing either to excessive stress as from a fall or a misstep or to fatigue of the nail.

Removal of the nail after healing of the fracture is probably not mandatory unless the nail is causing symptoms such as glu teal pain or an abductor type of limp It should not be removed in less than a year because of the risk of refracture If symptoms referable to the nail necessitate treat ment before this time the nail can be replaced with a shorter and slightly larger one.

Open Fractures of the Femoral Shaft

As in all open fractures the first and most important step in the definitive treat ment is an adequate debridement of the wound with removal of all foreign material and all contused and contaminated tissue All of the recesses of the wound should be thoroughly irrigated with sterile saline solution The surgeon must then decide whether immediate internal fixation is in

dicated or whether the wound should be closed and traction instituted In severely comminuted or shattered fractures traction is unquestionably the method of choice In transverse or short oblique fractures without gross contamination where debridement has been adequate and carried out within 6–8 hours from the time of injury fixation with an intramedullary nail may be indicated. If such ideal circumstances do not exist it is considered safer to close the wound and treat with traction. If primary healing of the wound ensues then further treatment may be instituted either by traction or preferably by a second operation when the soft tissues have recovered from the effects of trauma and the danger of sepsis is much reduced At this second procedure intramedullary fixation combined with onlay bone grafts should be employed

The wound closure at the time of debridement should be effected without tension and with meticulous care, to eliminate all dead space The skin, subcutaneous tissues and fascia lata may be left open if the condition of the wound is not entirely satisfactory A compression dressing with fluffed gauze and elastic bandages applied as a hip spica from toes to umbilicus may be indicated as support for the soft tissues while the fracture is immobilized either by traction or by intramedullary fixation as the case may be

A booster dose of tetanus toxoid should be given promptly provided that the patient has had a previous course of toxoid. Otherwise antitetanus should be injected intramuscularly after appropriate testing for sensitivity Should the patient be sensitive to horse serum appropriate measures must be undertaken to desensitize him so that an adequate dosage can be given

The prophylactic use of gas gangrene antitoxin is not recommended Antibiotics either singly or in combination and selected so as to give a broad antibacterial spectrum are certainly of value preoperatively and during the immediate postoperative period (See Chapter 33 on Treatment of Open Fractures)

Pathological Fractures

Pathological fractures of the femoral shaft due to metabolic bone disease or to bone destruction secondary to metastatic malignant lesions can be treated effectively with intramedullary fixation (See Chapter 8 on Pathological Fractures)

In the former instance fracture with metabolic bone disease considerable bowing of the shaft may be present, necessitating one or more osteotomies in order to straighten the shaft sufficiently to insert the medullary nail In spite of the extensive surgery necessary this method has been used successfully in fractures complicating osteogenesis imperfecta, in Paget's disease and in similar malacic diseases.

With metastatic lesions prompt relief of pain and early discharge home are usually possible after intramedullary fixation. If the patient survives long enough, the fracture may heal. Tumor cells are undoubtedly implanted throughout the shaft by the intramedullary nail there is both clinical and experimental evidence to indicate that such seeding does occur However the comfort afforded these patients and the opportunity to spend the remaining weeks or months of their lives at home far outweigh the danger of shortening their life expectancy

Complications

Delayed Union or Nonunion

The complication of delayed union or nonunion has probably resulted more commonly from inadequate plate and screw fixation with or without sepsis than from any other cause However distraction of the fracture surfaces due to excessive traction is a common factor as well Needless to say great care to avoid overpull is essential and in general open reduction should be undertaken only when sound fixation with an intramedullary nail is feasible

Once union is delayed or has failed to occur efforts should be directed toward eradicating sepsis if it exists securing adequate fixation and stimulating osteogen-

esis by onlay cancellous grafts from the ilium.

Sepsis may prove difficult to eradicate The first steps toward its eradication are of course the establishment of adequate dependent drainage posteriorly the excision of avascular scar tissue and of necrotic bone and sequestra the removal of broken or ineffective metallic apparatus such as plates and screws and immobilization of the fracture These fundamental surgical measures are the *sine qua non* of treatment. An auxiliary but secondary measure is the administration before surgery is undertaken of an effective antibiotic as determined by culture and sensitivity studies

Immobilization in most instances should be done by external means either a spica or traction and suspension Once the infection has been cleared up union may occur with prolonged immobilization or more probably a secondary procedure will have to be undertaken when there is reasonable assurance that sepsis will not recur This procedure should include exposure of the fracture site further excision of scar if necessary to secure a good vascular bed for the grafts freshening of the bone ends drilling-out of the medullary canal fixation with a medullary nail and placement of onlay grafts consisting of long cancellous shavings from the ilium around the fracture site Tibial cortical onlay grafts are probably never indicated in the treatment of femoral fractures intramedullary fixation and iliac grafts give much better results In an old established nonunion with a well-developed pseudoarthrosis and excessive sclerotic bone at the fracture site the excess sclerotic bone should probably be excised restoring the shaft to its more normal size

Needless to say supportive measures such as frequent blood transfusion and adequate protein intake are important both before and after operation

Considerable shortening of the femur frequently results from loss of bone substance due to sepsis from the excision of necrotic bone at operation or from both Such shortening is undesirable not only because of the resulting inequality of leg length but also because it decreases the efficiency of the already damaged quadriceps mechanism However union is of paramount importance and hence good contact of vascular bone ends must be achieved at all costs

Inevitably a far from satisfactory result is obtained in patient with shortening of the extremity and stiffness of the knee The plight of these patients should make all fracture surgeons undertake open reduction only after careful consideration of the indications for such treatment and only when ideal conditions for such surgery exist.

Under certain circumstances it may be advisable to use intramedullary fixation even in the presence of an open and infected fracture In selected cases this treatment has been used in old war wounds with gratifying results However this procedure should be undertaken only when more conventional methods are not applicable

In some cases bone union may take place in the presence of drainage but with obviously insufficient bone structure to prevent refracture Under these circumstances it may be possible to approach the fracture site through clean tissue usually anteriorly or medially without entering the sinus tract and under x ray control onlay grafts may be placed in healthy tissue in contact with the femur so as to reinforce the weakened area At a later date when bone of adequate strength has formed the sinus tract may be excised along with any necrotic bone which is present In this way it may be possible to eliminate the drainage

If delayed or nonunion exists in a closed fracture with no infection treatment should consist of adequate fixation supplemented with bone grafts Intramedullary fixation with iliac cancellous onlay grafts has proved eminently successful. It should be emphasized that here also a good vascular bed for the graft should be obtained by excision of avascular scar and sclerotic bone Needless to say the

medullary canal must be drilled out sufficiently to permit insertion of a medullary nail of adequate diameter (For discussions of bent or broken intramedullary nail and sepsis following intramedullary fixation see Chapter 32 on Operative Treatment of Fractures)

Impaired Knee Function

If for any reason, the knee has been immobilized for a prolonged period after fracture especially if union has been delayed or if sepsis has occurred limitation of flexion and extension will result due to joint adhesions and to scarring and adhesions of the quadriceps mechanism This is more likely to occur in distal fractures Where adequate intramedullary fixation has been achieved and active motion has begun early this complication is rare

In general, function plus prolonged physical therapy including progressive resistance exercises when appropriate will gradually restore a satisfactory if not a complete range of motion. If these measures fail some form of quadricepsplasty should be considered if the knee joint is intact. The technique described by Thompson for excision of the scarred portion of the quadriceps usually the vastus intermedius and release of the capsule and of the quadriceps expansions on both sides of the patella is probably the most satisfactory

The principles for the treatment of fractures of the femoral shaft are now well established In brief they are

1 In children skin traction by an appropriate method will give excellent results with few complications Immobilization in a spica with or without manipulation may be feasible in the very young Open reduction with internal fixation is rarely if ever indicated in this age group

2 In adults skeletal traction through the tibial tubercle is the safest method of treatment since it is applicable to almost every type of shaft fracture

3 Open reduction should be used only under ideal conditions and when fixation sufficiently stable to enable early mobilization with crutches is possible or in the rare situation where traction fails to gain satisfactory position Intramedullary fixation is the method of choice. If the fracture is such that this method of fixation is not suitable traction should be used The use of plates and screws is contraindicated except in rare instances

4 Onlay bone grafts preferably of cancellous iliac bone should be used in all open reductions except in rare instances.

5 Convalescent care and rehabilitation, including instruction in the proper use of crutches and the restoration of muscle power and joint function are essentials of treatment which cannot be neglected

6 An operative infection in fractures of the femoral shaft is such a disaster that open reduction should be undertaken only under the most ideal conditions

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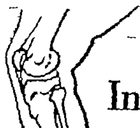
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27 

Injuries Involving the Knee Joint

THE KNEE IS A weight bearing joint which is subjected to a great variety of static and dynamic loads Normal knee function is possible only if there is good muscular control intact supporting ligaments and smooth and well aligned articular surfaces.

Acute trauma to this exposed joint is common particularly in the young adult who skis or plays contact sports such as football Automobile accidents produce "bumper" fractures in pedestrians and patellar or supracondylar fractures in the passengers.

GENERAL CONSIDERATIONS

Whether the primary injury is relatively minor and well localized or is more severe the clinical pattern following injury is characteristically that of pain, joint effusion and hamstring muscle spasm which produce a limping gait with the knee held rigidly in semiflexion There is a widespread misconception that if there is no fracture "it is all right to walk on it" Although mild soft tissue injuries tend to recover spontaneously the moderate and severe ones are extremely slow to recover and may leave permanent functional disability unless adequately treated. This implies correct diagnosis and the application of the necessary specific and general therapeutic measures

The specific measures will be discussed under the appropriate diagnostic headings. The general measures applicable to all types of knee injuries will be discussed here The core of skilled treatment lies in the use of rest and exercise at the proper time and in correct amounts.

REST

The injured knee should be put at rest and protected from further trauma and from unphysiological use until the injured tissues have healed and until good muscle control and joint motion have been restored The amount and type of rest that are necessary depend on the severity of injury In acute severe injuries such as occur in fractures or ligamentous ruptures complete bed rest for a few days with elevation of the knee at or above heart level is indicated

The method of protective immobilization will depend on the degree of severity of the injury A Thomas or Hodgen splint traction plaster casing or a posterior splint are commonly used for severe injuries Total immobilization should be dis-

continued as soon as it is safe to do so because its prolonged use produces muscle atrophy osteoporosis fibrosis of periarticular structures and thinning of articular cartilage

In the case of mild and moderate injuries crutches will protect the knee and still allow the patient to be quite active It

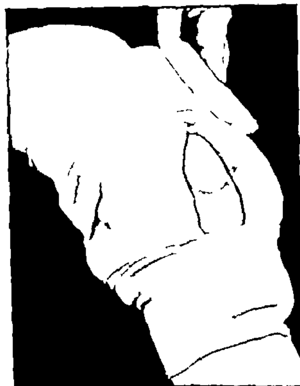


Fig 408 —Application of an elastic bandage over sponge rubber The suprapatellar pouch is obliterated but no direct pressure is placed on the skin overlying the patella (*outlined in ink*) Note the pad in the popliteal space

is not sufficient to prescribe the use of crutches the physician must explain why they are necessary and see that the patient is instructed and drilled in their proper use

In the acute phase of severe injuries with the knee immobilized in plaster no weight is borne on the injured extremity and the foot does not touch the floor In mild and moderate injuries and in the later phase of severe injuries the patient places the foot on the floor as the knee goes through its normal motions but the crutches take the body weight In this way smooth reciprocal flexion-extension muscle action is encouraged This increases venous and lymphatic return and stimulates restoration of normal physiology As the injured tissues heal the amount of weight borne on the crutches is gradually decreased until eventually the patient walks smoothly with full weight on the extremity Recurrence of pain muscle spasm or synovial effusion indicates that there is too much strain on the knee and that more weight needs to be carried on the crutches and less on the foot.

An elastic bandage applied over felt or sponge rubber is an efficient local support for the majority of the soft tissue injuries of the knee (Fig 408) The patient is taught to apply this support, with light and even pressure and to remove it for exercises several times daily

Light massage once or twice daily stroking from the ankle toward the upper thigh and preceded by the application of moist heat for 10–15 minutes helps to remove the excess synovial fluid and dissipate the soft tissue edema

Exercise

The amounts of rest and of exercise used in knee injuries bear a reciprocal *relationship In the acute* phase rest is maximal and exercise is minimal as recovery occurs rest is decreased and exercise increased

Atrophy of the quadriceps extensor musculature is the inevitable sequel of an acute knee injury and leads to chronic weakness of the knee musculature unless it is vigorously combated by appropriate exercises which are continued until normal strength has been restored

Quadriceps-setting exercises should be instituted immediately although where there is severe synovitis there may be difficulty in performing the exercises They should even be done when the leg is incased in plaster

Technique of Exercises —Both knees are placed in the extended position Preliminary heat and massage are helpful but

not essential. The patient is taught to con tract, voluntarily and simultaneously the quadriceps muscles of both thighs to a maximal amount. The contraction is sus tained for a count of 3 seconds and is then relaxed for the same period of time Em phasis is placed on slow forceful, complete contraction with an equal period of relaxa tion. Beginning with 5 repetitions the ex ercise is increased rapidly until the patient does 10 repetitions every hour during the day without difficulty This is followed by lifting the leg with the knee extended.

This type of quadriceps setting places no strain on injured tissues When the synovitis has subsided the exercise program is progressively increased until muscle strength has returned to normal, as shown by measurement of the circumfer ence of the two thighs

The graduation of exercise is carried out as follows

1 *Early Phase* —Quadriceps setting without resistance 5–10 times hourly

2 *Convalescent Phase* —Quadriceps setting lifting the leg off the bed with the knee extended 5–10 times hourly

3 *Late Phase* —Quadriceps drill (progressive resistive exercise) 10 times once daily The maximal amount of weight at tached to the foot or ankle which can be lifted with the knee fully extended is determined One half this amount is used for this exercise The weight is lifted with the knee fully extended The exercise is done slowly with the time of rest equal to the contraction time The maximal weight which can be lifted is redetermined at weekly intervals and the amount of weight (one-half maximal) to be used for the ex ercise program is adjusted accordingly

Knee Motion —As noted above com plete immobilization of the knee should be discontinued at the earliest possible moment and carefully graded active knee motion should be instituted. Motion should be kept within the limits of pain and muscle spasm and should not be forced in the first few weeks of recovery Underwater exercise is helpful. Such exercise may be done in a bathtub filled with warm wa

In the later phase of recovery lack knee flexion may be gradually overco by gentle assistive stretching over the e of a table and by squatting exercises.

Occasionally judicious gentle stre ing under anesthesia is necessary to h restore joint motion. The aim of treatm is restoration of normal muscle stren ligamentous stability and knee mot The severity of the injury may in so instances make it impossible to regai normal knee but adequate treatm based on the proper use of rest protecti and exercise can almost always res satisfactory function

SOFT TISSUE INJURIES OF THE KNEE

CONTUSIONS —Minor contusions oc frequently along the anterior aspect of knee over the patella the infrapatellar pad, and the tibial tubercle since th exposed sites are often injured by a di blow Severe injuries may result in hem rhage into the synovial membrane or infrapatellar fat pad The greatest po tial danger from a minor blow on the k is that the articular cartilage of the pat or of the femoral condyles may be d aged to such a degree that late degen tive changes—i.e chondromalacia or teochondritis—may occur

TRAUMATIC HEMARTHROSIS —Hem throsis of the knee usually denotes a vere knee injury It is most commonly sociated with fractures entering the jo less frequently with tears of the cruc or collateral ligaments After such inju swelling usually appears within the fir hours the pain is severe and the k temperature is increased Motion is limi and attended with pain The bony la marks are obliterated and on palpat there is a sense of doughy firmness.

TRAUMATIC SYNOVITIS —Synovitis companies almost all injuries to the kn It produces distention of the capsule w effacement of the anatomical landma In simple cases of "water on the kn

little pain is experienced and the symptoms are those of mild discomfort from tension and restricted motion. The appearance of the swelling is often delayed for some hours after the injury On palpation of the distended quadriceps pouch less firmness is noted than is present in hemarthrosis

TREATMENT —The treatment of contusions hemarthrosis and traumatic synovitis of the knee must be modified to meet the needs of the given injury but certain general principles are applicable to all types of knee injuries Rest of the joint is of the utmost importance Avoidance of the strain of weight bearing by the use of crutches will prevent further damage to a weakened knee The knee itself should be supported with an elastic bandage applied over a felt or sponge-rubber pad cut to fit around the patella. With more severe lesions particularly if there is a tendency to flexion deformity immobilization by means of a plaster cylinder and by bed rest may be indicated. The application of ice bags for the first 24 hours following the injury to the knee will lessen pain and joint distention. When danger of further bleeding has passed moist heat will produce a local hyperemia and aid in the phagocytosis of extravasated blood The use of excessive heat is injurious and should be avoided. Application for 10–15 minutes twice daily is sufficient.

Analgesics and sedation appropriate to the age of the patient and severity of the injury should be given as necessary

INJURIES OF THE LIGAMENTS OF THE KNEE

INJURIES OF THE INTERNAL COLLATERAL LIGAMENT

A valgus strain of the knee associated with twisting of the femur inward or of the tibia outward when the knee is slightly flexed is the usual cause of injury to the internal collateral ligament. The lesion varies from a minimal strain to complete rupture of both the superficial and deep portions of the ligament (Fig 409) The ligament may tear at any level or it may be avulsed from its tibial or femoral insertion In femoral detachments which are more common, a piece of bone may be torn away with the ligament If the force continues after the internal collateral ligament has given way the anterior cruciate ligament may rupture and the medial meniscus be injured.



Fig 409 —Tear of medial collateral ligament, avulsion of anterior spine and displacement of medial meniscus This x ray view taken with knee forced into valgus position under anesthesia demonstrates the wide gap at the medial joint line Note also the avulsion of the bony tibial insertion of the anterior cruciate

CLINICAL DIAGNOSIS —It is important to determine the true nature and degree of severity of the injury in order to prescribe proper treatment. With incomplete rupture or sprain of the internal collateral ligament pain is experienced on the inner side of the knee joint over the ligament Tenderness is localized at the site of the lesion. The knee is held slightly flexed and no instability can be demonstrated on attempt to force the extended knee inward

although pain is increased by this maneuver If the synovial lining is injured effusion ensues Hemarthrosis calls for diligent search to rule out the possibility of an unrecognized fracture

Should the ligament be completely ruptured there is often ecchymosis along the course of the ligament and joint effusion is present A sulcus may be felt at the level of the tear and abnormal lateral motion may sometimes be demonstrated by gentle manipulation without anesthesia

An estimation of the severity of the injury from the history together with examination of the knee clinically will usually satisfy a physician as to whether there is a partial or a complete tear of the ligament. However should a complete tear be suspected it is often advisable to test under anesthesia the integrity of the collateral ligaments the cruciate ligaments and the menisci Should the knee remain in a locked position of semiflexion following aspiration and anesthesia one must suspect a displaced meniscus Roentgenograms in anteroposterior lateral, and oblique views must be taken to rule out the possibility of avulsion fractures or of compression fracture of the tibial plateau

Conservative Treatment —In partial lesions of the internal collateral ligament treatment is directed to protecting the ligament from further strain relieving pain and restoring the power of the quadriceps muscle It is usually advisable to apply ice packs for the first 12–24 hours following which moist heat is beneficial in reducing the local swelling and ecchymosis The knee is placed at rest in about 5 degrees of flexion with either an Ace bandage a posterior molded splint or a plaster cylinder depending on the severity of the lesion Crutches are used for protection until the gait is normal Quadriceps exercises are practiced from the outset of treatment.

Operative Treatment —Certain surgeons advocate immediate operative repair of the internal collateral ligament in all complete tears whether isolated or associated with other injuries since experience has shown that the ruptured ligament, when treated by plaster immobilization may heal with a certain degree of laxity Operative repair is aimed at the restoration of a strong ligament and is best carried out as soon as possible after the injury before reparative changes have occurred in the damaged soft tissues Operative repair should be undertaken only if abnormal mobility can be demonstrated by examination (under anesthesia if necessary)

Technique —A longitudinal or bayonet incision will permit visualization of the entire course of the ligament. The fascia is incised and retracted. The site of the lesion and the extent of the damage are evaluated.

If both the deep and the superficial layers of the ligament are torn each layer should be sutured separately When the ligament is avulsed from its tibial or femoral insertion, it is treated by suture with a wire or silk through drill holes When the superficial layer of the ligament alone is detached at its insertion, it may be possible to obtain satisfactory repair by a suture to the underlying soft tissues and periosteum When the avulsion carries with it a portion of its bony insertion the fragment of bone is replaced and fixed by a wire or silk suture

Injuries of the External Collateral Ligament

The external collateral ligament is much less frequently injured than the internal collateral ligament. The injury usually occurs at the fibular attachment of the ligament and often it pulls with it a fragment of bone There may be associated damage to other nearby structures—i.e the capsule popliteus tendon or iliotibial band and the cruciate ligaments In rare instances the common peroneal nerve may be stretched or ruptured. A tear of the lateral collateral ligament is suggested by the history of a varus strain followed by the clinical manifestations of localized pain, swelling and tenderness As in the case of the medial collateral ligament should the severity of the injury by history and physi-

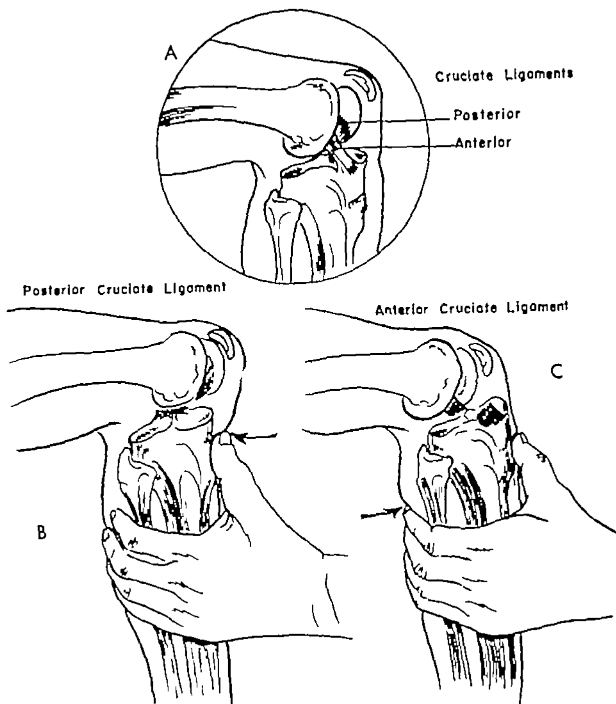


Fig 410 —A, sketch demonstrating the cruciate ligaments B posterior "drawer" sign for rupture of the posterior cruciate ligament C, anterior "drawer" sign demonstrating anterior cruciate rupture

cal examination suggest a complete avulsion of the ligament examination under anesthesia should be undertaken comparing the injured with the normal joint. Definite widening of the lateral joint space may be demonstrated in roentgenograms. Surgical repair in complete ruptures is effected by methods similar to those used in repair of the internal collateral ligament. If there is evidence of peroneal nerve involvement the nerve should be exposed at the time of surgical repair of the ligament Usually the nerve is stretched rather than divided but the prognosis for functional recovery is poor in either case Occasionally successful suture is possible

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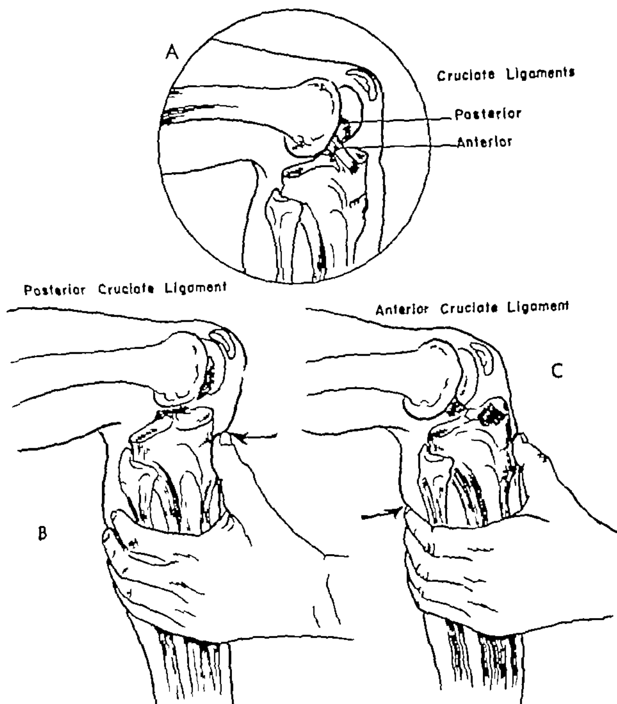


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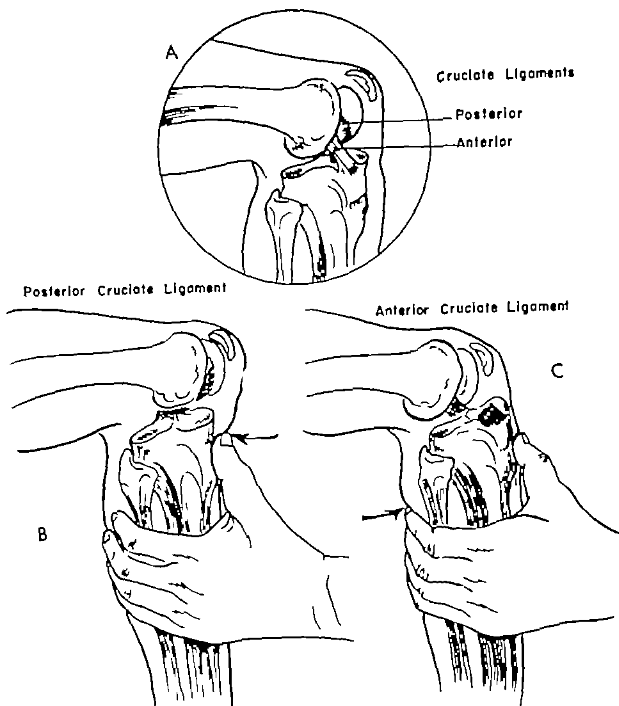


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Should the ligament be completely ruptured there is often ecchymosis along the course of the ligament and joint effusion is present A sulcus may be felt at the level of the tear and abnormal lateral motion may sometimes be demonstrated by gentle manipulation without anesthesia

An estimation of the severity of the injury from the history together with examination of the knee clinically will usually satisfy a physician as to whether there is a partial or a complete tear of the ligament. However should a complete tear be suspected it is often advisable to test, under anesthesia the integrity of the collateral ligaments the cruciate ligaments and the menisci Should the knee remain in a locked position of semiflexion following aspiration and anesthesia one must suspect a displaced meniscus Roentgenograms in anteroposterior lateral, and oblique views must be taken to rule out the possibility of avulsion fractures or of compression fracture of the tibial plateau

Conservative Treatment —In partial lesions of the internal collateral ligament treatment is directed to protecting the ligament from further strain relieving pain and restoring the power of the quadriceps muscle It is usually advisable to apply ice packs for the first 12–24 hours following which moist heat is beneficial in reducing the local swelling and ecchymosis The knee is placed at rest in about 5 degrees of flexion with either an Ace bandage a posterior molded splint or a plaster cylinder depending on the severity of the lesion Crutches are used for protection until the gait is normal Quadriceps exercises are practiced from the outset of treatment

Operative Treatment —Certain surgeons advocate immediate operative repair of the internal collateral ligament in all complete tears whether isolated or associated with other injuries since experience has shown that the ruptured ligament when treated by plaster immobilization, may heal with a certain degree of laxity Operative repair is aimed at the restoration of a strong ligament and is best carried out as soon as possible after the injury before reparative changes have occurred in the damaged soft tissues Operative repair should be undertaken only if abnormal mobility can be demonstrated by examination (under anesthesia if necessary)

Technique —A longitudinal or bayonet incision will permit visualization of the entire course of the ligament The fascia is incised and retracted. The site of the lesion and the extent of the damage are evaluated

If both the deep and the superficial layers of the ligament are torn each layer should be sutured separately When the ligament is avulsed from its tibial or femoral insertion, it is treated by suture with a wire or silk through drill holes When the superficial layer of the ligament alone is detached at its insertion it may be possible to obtain satisfactory repair by a suture to the underlying soft tissues and periosteum When the avulsion carries with it a portion of its bony insertion the fragment of bone is replaced and fixed by a wire or silk suture

Injuries of the External Collateral Ligament

The external collateral ligament is much less frequently injured than the internal collateral ligament. The injury usually occurs at the fibular attachment of the ligament and often it pulls with it a fragment of bone There may be associated damage to other nearby structures—i.e the capsule popliteus tendon or iliotibial band, and the cruciate ligaments In rare instances the common peroneal nerve may be stretched or ruptured A tear of the lateral collateral ligament is suggested by the history of a varus strain followed by the clinical manifestations of localized pain swelling and tenderness As in the case of the medial collateral ligament should the severity of the injury by history and physi

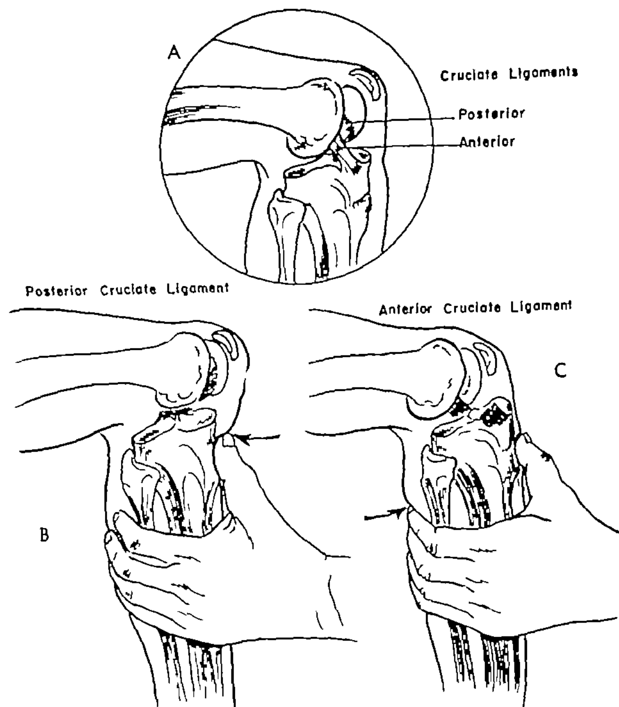


Fig 410 —A, sketch demonstrating the cruciate ligaments B posterior "drawer" sign for rupture of the posterior cruciate ligament. C anterior "drawer" sign demonstrating anterior cruciate rupture

cal examination, suggest a complete avulsion of the ligament examination under anesthesia should be undertaken comparing the injured with the normal joint. Definite widening of the lateral joint space may be demonstrated in roentgenograms Surgical repair in complete ruptures is effected by methods similar to those used in repair of the internal collateral ligament. If there is evidence of peroneal nerve involvement the nerve should be exposed at the time of surgical repair of the ligament Usually the nerve is stretched rather than divided but the prognosis for functional recovery is poor in either case Occasionally successful suture is possible

In late cases neurolysis may result in some improvement in nerve function

Injuries of the Anterior Cruciate Ligament

Avulsion Fracture of the Tibial Spine Isolated Lesions —Isolated lesions of the anterior cruciate ligament may occur as the result of a direct blow on the posterior aspect of the upper tibia, displacing the tibia forward on the femur or conversely a blow on the anterior femur may produce the lesion. The ligament may be stretched or ruptured at its upper attachment in the central portion or at its tibial insertion and in this case there may be detachment of a fragment of bone from the tibial spine Severe torsional strains produce combined lesions involving the semilunar cartilage the anterior cruciate ligament and the medial collateral ligament.

Examination reveals joint effusion and restricted motion Satisfactory clinical examination may be impossible until the joint has been aspirated or until muscle spasm has been eliminated by administering a general anesthetic The characteristic clinical sign of stretching or rupture of an anterior cruciate ligament is abnormal forward mobility of the tibia on the femur as compared with that on the uninjured side when the knees are examined in the position of 90-degree flexion—the so-called "drawer" sign (Fig 410) Roentgenograms may demonstrate a fragment of bone detached from the tibial spine (Fig 411)

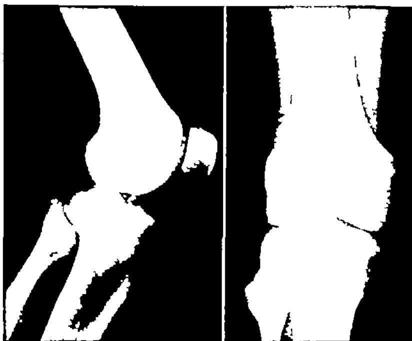


Fig 411 —Lateral and anteroposterior views of avulsion fracture of the anterior tibial spine, showing fragment of the anterior spine lying within the joint. The anterior cruciate ligament is attached to this fragment.

Conservative Treatment —The treatment of avulsion of the tibial spine depends on the degree of displacement of the fragment. When the displacement is slight operative intervention is not necessary In such a case the joint is immobilized in a plaster cylinder with the knee in the position of extension for a period of 6–8 weeks Aspiration of the joint prior to application of the plaster cylinder helps in reducing the acute pain.

Operative Treatment — In avulsion fractures of the tibial attachment of the anterior cruciate ligament with displacement the knee cannot be completely extended and operative reduction and fixa

tion of the fragment in situ is necessary

Technique —The knee joint is approached through an anteromedial curved incision. The fascia and capsule are incised and the patella is displaced laterally allowing full inspection of the injury If the semilunar cartilage *attachments* are damaged one or both of the semilunar cartilages may need to be removed The fractured tibial spine is then replaced and secured as shown in Figure 411 1 A plaster cylinder is applied with the knee in extension, for 3 weeks and quadriceps exercises are practiced throughout the course of treatment. Consolidation of the fragments must be complete before unprotected weight bearing and full activity are resumed Usually a period of 6–8 weeks is required

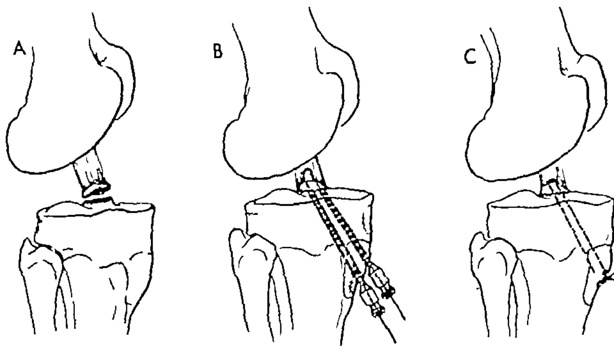


Fig. 411 1 —Repair of avulsed anterior tibial spine A lateral view Pulling off of anterosuperior spine by anterior cruciate ligament. B suture of spine by inserting a No 28 stainless steel wire through No. 15 *intravenous needles placed* in drill holes and through avulsed fragment C, needles are removed, wire is tightened apposing displaced tibial spine and 2 ends of wire twisted snugly together

Injuries of the Posterior Cruciate Ligament

Avulsion Fracture of Attachments of the Ligament —A direct blow on the semi flexed knee forcing the tibia backward is the usual cause of this injury The lesion is sometimes observed following an automobile accident in which a person is thrown forward striking the knee against the dashboard *Avulsion of the ligament* may take place at its tibial insertion lifting *a fragment of bone from the tibial surface* or a rupture may occur at the attachment of the ligament on the medial femoral condyle The history of an injury of the type described followed by instability and hemarthrosis of the joint suggests *damage to the posterior cruciate ligament* The positive diagnostic sign is abnormal *backward mobility of the tibia on the femur* with the knee in 90-degree flexion—the posterior "drawer" sign (Fig 410) Aspiration of the joint and muscle relaxation obtained by administering a general anesthetic may be necessary before this test can be made A roentgenogram may demonstrate a detached fragment of bone

Treatment —An avulsion fracture of *the tibial attachment of the posterior cruciate ligament* with no displacement may

be treated by aspirating the joint and then applying a plaster cylinder with the knee slightly flexed. Immobilization is continued for at least 6 weeks Rarely if ever is sur gery indicated A plaster casing is applied to the knee which is flexed to about 15 degrees Quadriceps exercises should be practiced regularly and recovery may be expected in 6–8 weeks

INJURIES OF THE SEMILUNAR CARTILAGES

Traumatic lesions of the menisci have a well recognized etiology in the form of a rotatory strain of the knee joint. Such strains are often sustained in dodging movements in running or in "contact" ath letics such as football or the kicking move ment of soccer and in certain occupations requiring a crouching position and twist ing of the body such as telephone line re pairing and mining Hence injuries of the menisci are most common among males and in persons aged 18–40 the period of greatest physical activity

Statistically it has been shown that injuries of the medial meniscus are far more prevalent than lesions of its lateral coun terpart. This greater frequency may be ex plained by the variation in the anatomical relations of the menisci The medial semi lunar cartilage is firmly attached to the tibial collateral ligament, and it is also bound to the articular capsule along its peripheral border whereas the external meniscus is not closely adherent to the capsule or the fibular collateral ligament. The internal meniscus glides backward and forward on the tibia and may be pinched between the apposing articular surfaces of the tibia and femur during a rotatory strain.

INJURIES OF THE MEDIAL MENISCUS

The mechanism of this injury is usually an inward twisting of the femur on the tibia combined with a weight-bearing strain when the foot is in a fixed position and the knee is being forcibly extended from the flexed position. The medial meniscus may be torn longitudinally transversely or obliquely in varying patterns A split may occur in the posterior central, or anterior segment or along the periphery of the cartilage If the capsular attachment of the meniscus is unusually relaxed or there is a marginal tear in its periphery the meniscus as a whole or its major part, may be displaced toward the center of the joint (the "bucket handle" tear) At the time of the injury there is considerable pain and invariably the feeling that the knee has given way Following the trauma the joint becomes swollen and tender and motion is restricted In many cases it is impossible to straighten the knee the so-called "locking" of the joint.

Often a person fails to consult a physician after the initial attack unless the joint remains locked Return attacks are experi enced however although the symptoms tend to be less severe and subside more rapidly even locking of the joint being only transitory Conversely subsequent attacks may occur on slight twisting movements of the knee The person experienc ing these recurrences develops a constant fear that the joint may give way at any time

The diagnosis of a meniscal disorder is made without difficulty in the majority of cases although it is not always possible to determine the extent exact location, or type of the lesion If a history of a twisting strain is obtained and the joint is locked there is little doubt that the cartilage is torn and a segment displaced The patient with a locked knee is unable to extend the joint fully and any attempts to straighten the extremity cause pain and are met with a rubbery resistance In view of the fact that a similar limitation of extension of the joint is encountered in a traumatic synovial effusion subsequent to other le sions it may be necessary to aspirate the joint to determine the presence of true locking. Differentiation is particularly important when the patient is unable to give a reliable description of the type of ini tiating injury

In cases without locking, the most de-

pendable diagnostic feature is the history in which will be detailed the primary injury of a twisting strain accompanied by pain and swelling tenderness and limitation of motion the recurrence of similar attacks and the ever present fear that the knee may give way at any time

Clinical evaluation of the knee with a suspected meniscus injury requires not only a careful analysis of the mechanism of injury involved but also a detailed local physical examination, consisting of inspection palpation and testing for motions and stability as well as observation of stance and gait Palpation of the joint line may reveal thickening anterior to the lateral ligament usually more evident as the knee is brought from flexion to the extended position Palpable thickening over the posterior portion of the internal semilunar cartilage indicates a probable tear of that portion of the meniscus

If the lesion is of long standing and has gone untreated disability is increased by repeated damage to the joint. The capsule and collateral ligaments may be weakened from intermittent effusion. There may be chronic or recurrent joint effusion. The quadriceps muscle may be atrophied causing the patient to limp The articular cartilage of the joint may be fibrillated and bony exostoses may develop as a late sequela Roentgenograms should be taken to rule out other lesions such as calcified cartilaginous loose bodies

The treatment of the primary acute meniscal injury may be either conservative or operative the latter measure consisting of excision of the offending semilunar cartilage. To a certain extent the choice of treatment is based on an understanding of the usual repair process Except at the peripheral attachment of the meniscus to the joint capsule there is no blood supply to the structure and consequently a tear can be expected to heal only if it is situated at the periphery It has been pointed out however that the true nature of the lesion cannot always be determined and there are many cases in which it is even impossible to diagnose a meniscal injury accurately from the clinical and roentgenological examination For this reason conservative management is considered to be the treatment of choice in a primary derangement There are few surgeons who advocate excision of the meniscus after the initial injury unless the knee is locked

Conservative Treatment — Aspiration of the joint is indicated in those cases presenting a severe joint effusion If the knee is not locked the extremity may be immobilized in a posterior plaster splint in the position just short of maximum extension Quadriceps-setting exercises are initiated immediately and the patient carefully instructed to continue with them at stated intervals throughout the waking hours Walking with crutches with partial weight bearing is permitted in approximately 10 days Immobilization for 3 weeks is adequate in the average case On removal of the plaster cylinder more intensive exercises of the quadriceps muscles are begun. Throughout the entire course of treatment the importance of improving the tone of the thigh muscles should be impressed on the patient When normal muscle strength and a full range of motion have been regained the patient is allowed full activity

Operative Treatment —Surgical excision of a damaged meniscus is indicated when there is a history of recurrent episodes of locking or giving away of the knee joint with accompanying symptoms of pain, swelling, and tenderness If the cartilage is not removed the damage to the joint structures from repeated derangement of the meniscus leads to degenerative changes Operative excision of the cartilage is also indicated in an initial derangement with locking of the joint which proves to be irreducible by manipulative measures

Prior to operation attention should be focused on improving the strength of the quadriceps extensor muscle The patient should be instructed in quadriceps contraction and resistance exercises which should be practiced faithfully for several days before the operation

Technique —The surgical approach may be made with or without a tourniquet and

the type of incision should be one that allows adequate inspection and complete removal of the meniscus including its posterior attachment. The A. G T Fisher or the Robert Jones approaches allow free access to only the anterior compartment of the joint and with these incisions it may not be possible to remove adequately the posterior portion of the meniscus The Cave and the Bosworth incisions permit removal of the entire meniscus without damage to the articular surfaces or the col lateral ligaments None of the foregoing incisions however is adequate for com plete inspection of the opposite side of the knee In cases where complete exploration is required the use of two incisions is recommended one medial and the other lateral Two such incisions give better ac cess to the joint with less trauma than does the single extensive medial parapatellar incision

Postoperative Care.—The knee is im mobilized by means of a compression bandage or a posterior splint and quadri ceps contraction exercises are practiced as soon as the patient is comfortable In about a week or 10 days the patient may begin to walk with the aid of crutches bearing par tial weight. On removal of the compression bandage usually within 2 weeks active motion of the knee joint is begun When quadriceps strength is considered to be sufficient to support the extremity and to allow the patient to walk without a limp crutches may be discarded.

Injuries of the Lateral Meniscus

Lesions of the lateral meniscus occur far less frequently than injuries of the in ternal cartilage owing principally to the anatomical variation in mobility of the two structures and to the rarer occurrence of the reverse rotatory strain which dam ages the external meniscus A lesion of the lateral meniscus is usually the result of an internal rotatory strain of the tibia on the femur Not infrequently the tear oc curs in the posterior segment of the car tilage As a rule the symptoms are mild pain, usually localized at the outer side of the joint is slight and effusion is mini mal Locking of the joint is not common but there may be a history of recurrent attacks of giving way of the joint Tender ness may be elicited along the external joint line Lesions located in the posterior or anterior segments of the cartilage may be identified by a click that is elicited in the case of posterior horn damage when the knee joint is fully flexed and then slowly extended

Treatment —The same principles ap ply in the management of injuries of the external meniscus as in the treatment of internal meniscal damage

Combined Lesions of the Medial Meniscus & the Internal Collateral & Anterior Cruciate Ligaments

It has been pointed out earlier in this chapter that rupture of the anterior cruci ate ligament and injury to the medial me niscus may be associated with an injury to the medial collateral ligament In some cases the meniscus is displaced into the intercondylar notch locking the joint This triad of lesions should be suspected in all severe knee injuries and is particularly common as the result of the "clipping" football injury (Fig 409) Symptoms and signs pointing to a lesion involving each of these structures as described above will be found if the knee is carefully and completely examined Aspiration of the knee and examination under anesthesia will often prove helpful.

Treatment —Acute severe injuries in volving the internal collateral ligament, the anterior cruciate ligament and the in ternal meniscus should be treated opera tively repairing the collateral and cruciate ligament tears and if the internal menis cus is found to be torn or displaced it should be removed Conservative treat ment of combined lesions is the method of choice if the knee is not locked and if on examination under anesthesia there is minimal lateral and anteroposterior insta

bility The treatment outlined for medial collateral ligament tears is then followed

LESIONS OF THE KNEE EXTENSOR APPARATUS

Disruption of the quadriceps extensor apparatus (Fig 412) may occur at various levels for example there may be avulsion of the proximal attachment of the rectus femoris at the anteroinferior iliac spine rupture of the muscle components at any point in the thigh rupture or avulsion of the quadriceps tendon at the upper margin of the patella with or without a small frag ment of the patella itself transverse frac tures of the patella itself and rupture of the patellar tendon or avulsion of its bony insertion Each is a characteristic injury of a certain age group Surgical interven- tion is a necessity in many of these in juries

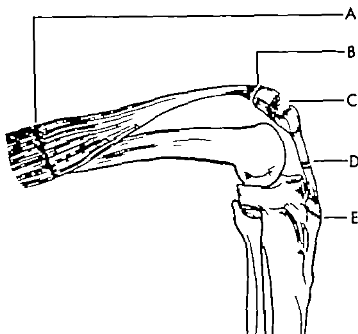


Fig 412.—Common injuries of extensor mechanism of the knee A tear of quadriceps mus- cle B avulsion of quadriceps tendon C fracture of patella (tear of quadriceps expansion not shown in sketch) D laceration of patellar tendon E avulsion of tibial tubercle

Muscle Ruptures

Young adults participating in contact athletics often sustain this type of injury as a result of a direct blow to the quadri- ceps muscle at the level of midshaft of the femur Occasionally violent contrac tion of a single muscle group will result in a small tear The vastus internus and rec- tus femoris muscles are the usual site of trauma the degree varying from simple contusion to deep laceration.

The clinical diagnosis of a fresh lesion is based on the history of an injury in the form of a blow or violent contraction of the quadriceps muscle with subsequent pain, local hemorrhage and swelling Ten derness may be elicited over the involved area. Ecchymosis is visible 2–3 days after the injury When the symptoms are mild there is seldom an opportunity to diagnose a recent rupture because the average per son with the well known "charleyhorse" rarely seeks medical advice unless compli cations develop

Treatment —Treatment comprises the simple measures of bed rest or crutches depending on the severity of the injury and the application of a compression band age and cold compresses With the sub- sidence of pain exercises are instituted to restore joint function and muscle strength

The installation of procaine and hyaluronidase into and around the area of maximal swelling and the application of a firm pressure dressing to hasten the dispersion of the hematoma may be of value

The possibility of late development of myositis ossificans traumatica in ruptures of the quadriceps muscles and particularly subsequent to lesions of the vastus intermus group must be kept in mind In the event that such a complication does develop the treatment is conservative consisting of immobilization and rest of the involved area until the metaplasia ceases Surgical removal of new bone formation should not be undertaken in the early stages of ossification such surgery is rarely if ever necessary Resection prior to maturation will only lead to new and more extensive bone formation Physiotherapeutic measures such as massage passive motion and diathermy are strictly contraindicated during the acute stage The extremity should be carefully protected from further injury

The differential diagnosis between myositis ossificans and osteogenic sarcoma may be difficult A careful history and physical examination and a roentgenological study will usually establish diagnosis

Rupture of the Quadriceps Tendon

This injury usually occurs in older persons whose muscles and tendons are losing their strength and elasticity and who may be overweight Sudden contraction of the quadriceps muscle against the opposing resistance of the knee fixed in flexion is the usual mechanism of injury The patient gives a history of having stumbled when going downstairs and of making a violent effort to keep his balance The rupture may be accompanied by intense pain as the knee gives way

The tendon may be torn completely across often taking with it small fragments of bone from the superior pole of the patella or the tear may occur through the tendon or at the musculotendinous junction The diagnosis depends on the history and on the clinical findings of local tenderness displacement of the patella distally the presence of a palpable sulcus and loss of active extension of the knee joint It should be borne in mind that extension of the knee is possible if the tear is incomplete With the tendon torn the sulcus becomes more distinct on contraction of the quadriceps also the contour of the thigh changes because of abnormal function of the quadriceps muscles during contraction Ecchymosis of varying extent is usually observed in injuries of this type

Treatment —Operative intervention is indicated to repair complete tears The earlier the operation is performed, the easier the repair is executed and the better the prognosis When the lesion is treated promptly healing is complete in 5–6 weeks However the strength of the quadriceps and therefore the stability of the knee will be impaired for many weeks There are many methods of repair (e g the Campbell and the McLaughlin methods) The surgical technique and suture material varies according to individual preferences A thin strip of fascia lata woven across the defect is a very satisfactory method of repair (See Fig. 549)

Avulsion of Ligamentum Patellae

Avulsion from the Patella

Avulsion from the patella in contradistinction to rupture of the quadriceps at the upper pole of the patella appears in youth The mechanism of injury however is the same—namely forceful contraction of the quadriceps with the knee flexed and the leg in a fixed position As a rule not only are the tendon fibers avulsed from the patella but the lateral expansions of the quadriceps are also torn The diagnosis in acute cases is made without difficulty Intense pain inability to extend the leg local tenderness swelling, and ecchymosis are indicative features Displacement of the patella proximally on contraction of the

quadriceps mechanism is obvious A defect is palpable between the patella and the detached tendon

TREATMENT —Early operative repair of the tendon defect is indicated Surgical methods of choice are the approximation of the tendon directly to the patella by wire or silk or the pull-out method described by McLaughlin Tears in the lateral expansions of the quadriceps mechanism must also be carefully repaired

Avulsion from the Tibial Tubercle

Occasionally the quadriceps extension mechanism is avulsed from its bony insertion into the tibial tubercle or the tubercle itself is fractured In either case clinical examination will reveal swelling local tenderness and displacement of the patella proximally with a palpable defect at the insertion of the patellar tendon into the tibial tubercle A roentgenogram will demonstrate a detached fragment of bone

TREATMENT —Early operative repair is indicated When a large fragment of the tibial tubercle is detached with the tendon it is usually possible to replace the fragment in normal position and stabilize it by means of a screw In cases of isolated avulsion when only a small fragment of the tibial tubercle is avulsed with the ligament a new anchorage for the tendon may be created, as described by Palmer As with all previously described extensor tendon injuries early active joint motion is encouraged upon the subsidence of the acute symptoms The surgical repair for this reason must be secure

TRAUMATIC DISLOCATION OF THE PATELLA

Traumatic dislocation of the patella (Fig 413) in a normal knee is not a common injury Luxation is practically always to the lateral side and is usually the result of a blow to the medial surface of the patella or sudden adduction and flexion of the knee If trauma occurs when the quadriceps muscle is relaxed dislocation may be complete Damage to the quadriceps expansion capsule and synovial membrane on the inner side of the knee as well as injury to the vastus medialis accompanies a lateral dislocation Reduction is often spontaneous on extension of the knee or a bystander may thrust the patella



Fig 413 —Traumatic dislocation of patella associated with lateral plateau fracture

back into normal position Occasionally general anesthesia may be necessary before reduction can be carried out

The surgeon consequently seldom sees the patella in its dislocated state The diagnosis must be based on the history and the clinical findings of swelling synovitis and tenderness on the medial aspect of the patella. Since these manifestations are equivocal the differentiation between patellar dislocation and an injury to the internal meniscus may present some difficulty

TREATMENT —A dislocation of the patella, except in an unusual case may be reduced by manipulation without general anesthesia. It is only necessary to extend

the knee and to restore the patella to the anatomical position by pressure Surgical intervention is indicated in a rare case when the medial parapatellar structures and capsule have been severely lacerated and must, therefore be repaired

If the patella has already been reduced when the surgeon sees the patient for the first time the extremity is immobilized in a walking cylinder for 3 weeks Restoration of extensor muscle power is attained by quadriceps exercises as noted on page 513

Recurrent dislocation of the patella is not as a rule the direct result of trauma and is not discussed in this chapter

FRACTURES OF THE PATELLA

Fractures of the patella may be divided into two major groups the transverse fracture and the comminuted fracture distinguished by the mechanism of the fracture the associated pathological process and the method of treatment.

The transverse fracture (Fig 414) in most instances is produced by a sudden and violent contraction of the quadriceps muscle The patella is snapped cleanly across in two fragments almost equal in size Less often the fracture lies near the upper or lower poles of the patella. A transverse fracture is likely to occur when a person tries to prevent himself from slipping or falling as his heel is caught Less frequently a direct blow may be the cause of the fracture Such a fracture has occurred in an attempt to mobilize a stiff knee joint when manipulation under general anesthesia was too forceful

Tears of the quadriceps expansion to the medial and lateral sides of the fracture

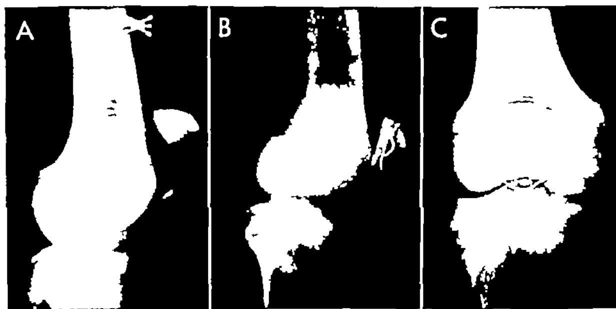


Fig 414 —A, transverse fracture of patella. B and C, treated with encircling wire Note the separation of the fragments denoting capsular tears Fascia lata may be used in place of wire

site are usually associated with displaced transverse fragments At times the tears may extend for 2 or 3 inches radially from the fracture and usually they include both the knee joint capsule and its synovial lining (Fig. 415) Because the fracture communicates with the joint, there is an effusion and exudation of blood into the joint cavity Roentgenograms fail to show the severe associated soft tissue damage associated with a transverse patellar fracture

Retraction of the quadriceps muscle pulls the proximal fragment upward The degree to which the fragments separate depends principally on the extent of the tear in the quadriceps expansion and joint capsule It is not unusual for the fractured

surface of the distal fragment to be tilted anteriorly and to be covered by fibers of the prepatellar fascia.

The second category of patellar fractures is the *comminuted type* (Fig 416) which is produced by a direct blow in which the patella is crushed against the

The diagnosis of a recent fracture of the patella can usually be made without difficulty from a study of the mechanism of the injury and from the clinical manifestations of pain local tenderness and limited motion with the inability to bear weight The quadriceps mechanism has a

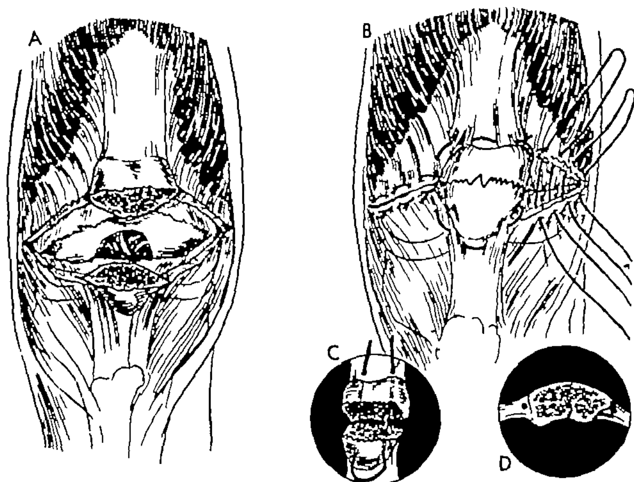


Fig 415 —A, fracture of patella with separation There are associated tears of the quadriceps expansion and underlying synovia B synovia closed with interrupted sutures Heavier mattress sutures are placed in expansion and tied following accurate approximation of the patellar surface under direct vision The patella may be fixed with encircling fascia lata or stainless-steel wire C, alternate method of patellar fixation D central placement of the encircling wire to prevent angulation of the fragments

femoral condyles The bone is broken into three or more fragments or is completely shattered Displacement may be slight. In contrast with the transverse fractures the quadriceps expansion and joint capsule are seldom extensively lacerated. However the articular cartilage of the patella and its opposing femoral surface are usually damaged and this affects the eventual prognosis.

direct connection to the patellar tendon through the lateral and medial quadriceps expansions If these are not significantly torn, the patient may be able to hold the extremity extended against gravity or to extend the knee from a flexed position Roentgenograms must always be taken Transverse fractures with separation of the fragments usually have a palpable sulcus between the fragments Active exten



Fig 416 —Left lateral view of comminuted fracture of patella. Note the multiple fracture lines. In this case the wide separation of fragments indicates tears of the quadriceps expansion Treatment consisted of patellectomy (right) and repair of quadriceps expansion



Fig 417 —Bilateral tripartite patella. Tangential views of both patellas Note the smoothness and round corners of the cleavage planes This is an anatomical variation and is not to be mistaken for a fracture

sion of the leg is impossible and the attempt is painful

A fracture of the patella must not be confused with congenital bipartite or tripartite patella (Fig. 417) Careful study of the films will reveal the sharply delineated fracture line of a traumatic lesion which is in contrast with the smooth often angulated line of cleavage and zones of increased density found in developmental variations Differentiation must likewise be made from Larsen Johansson disease in which secondary centers of ossification are present, usually at the inferior border of the patella. The correct diagnosis should be readily established from the history and the clinical and x ray examinations. Anatomical variations of the patella are frequently bilateral and therefore films should include both knees

Care must be taken also not to over look a fracture of the patella when atten tion is directed to more obvious injuries For example a patellar fracture may be associated with a posterior dislocation of the hip in a dashboard type of injury

Fractures of the patella call for prompt, definitive treatment to assure rapid func tional restoration of the knee If operative intervention is necessary it should be car ried out as soon as possible Usually the local conditions are most favorable in the first few hours after injury If operation is delayed, joint effusion ecchymosis tissue swelling and local necrosis or bleb forma tion of the skin make operation difficult and add to the hazard of postoperative in fection.

Transverse Fractures of the Midpatellar Region

Conservative Treatment — When roentgenograms reveal little or no separa tion of the fragments indicating that the quadriceps mechanism is intact conserva tive treatment may be elected Attention is first directed to aspirating the blood from the knee joint. If necessary aspirations may be repeated every 24 hours for the first 3–4 days This will aid considerably in the general comfort of the patient by re-lieving the distention of the joint. The ex tremity is protected by a posterior plaster splint extending from ankle to groin with the knee in extension. When the pain sub-sides the patient s functional recovery will be helped by early quadriceps-setting exer cises gentle assisted motion and ambula tion with crutches Within 6 weeks the fragments are usually sufficiently consoli dated so that graduated active exercises and weight bearing assisted by crutches may be instituted with the objective of re-storing quadriceps strength and knee mo-tion. Full weight bearing is allowed when the range of motion of the knee and the strength of the quadriceps mechanism per mit a smooth gait

Operative Treatment —When the fracture line divides the patella into nearly equal fragments which are separated to a varying degree operative reduction is in dicated if the condition of the patient warrants The success of the procedure de-pends on two factors (1) accurate re alignment of the articular surface of the fragments and (2) precise repair of the quadriceps expansion apparatus The frag ments must be fixed in perfect anatomical position for if any irregularity remains in the articular surface of the patella, chon dromalacia and osteoarthritis will develop Attention has already been called to the tears in the strong quadriceps expansions on either side of the patella which are al ways associated with transverse fractures Unless these structures which are vital to the strength and function of the knee joint, are properly repaired active motion in the joint will be considerably impaired particularly in the last 15 degrees of ex tension

Technique —A shallow U shaped inci sion just below the lower pole of the pa tella will expose not only the entire patella but also the quadriceps expansions on either side The fractured surfaces are sep-arated and the knee joint is inspected Blood clots bone chips and tags of fibrous tissue and cartilage are removed from the joint, which is then thoroughly irrigated with sterile saline solution The lateral and medial tears are next repaired A very fine continuous plain catgut suture is used to approximate the synovial layer The cap-sular tear is repaired by placing inter rupted silk or catgut sutures so that the suture material does not enter the joint The sutures are placed but are not tied un-til the bone fragments have been fixed The fragments are accurately reduced and held by a clamp or large towel clips In ternal fixation is always used to maintain the bone fragments in position The most popular suture material is fascia lata or stainless-steel wire Several different meth ods of placing the suture material have been advocated Any method to be satis-factory must permit tightening of the su

ture without the danger of producing angu lation or rotation of the fragments (Fig 415 *D*)

A strip of fascia lata ¼ inch wide may be used as suture material. This is obtained from the lateral aspect of the thigh by means of a fascial stripper The strip is threaded along the periphery of the patella to completely encircle it the two ends are drawn tightly together and the knot is secured with silk (see also Figs 414 and 415) The previously placed sutures on the



Fig 418 —Left polar fracture of patella with comminution Right view after excision of distal pole and suture of patellar tendon into proximal fragment. In this case an acceptable alternative procedure might have been total patellectomy

expansion tears are then tied and the skin closed

Postoperative Care.—The method of postoperative immobilization will vary with the surgeon s judgment as to the security of the fixation of the fragments When there is no question as to the stability the extremity may be placed on a Hodgen splint with a Pearson attachment, thus allowing quadriceps exercises and ac tive flexion and extension of the knee joint within the limits of pain If there is doubt concerning the security of fixation a plaster cylinder is applied with the knee in extension.

Quadriceps exercises are begun prompt ly after the operative reaction has subsided The cylinder is removed within 3–4 weeks and graduated exercises are per mitted to restore the quadriceps strength and joint motion. In the average case at least 4–6 months will be necessary before a satisfactory range of motion and full quadriceps power is regained. In some severe injuries normal muscle power and a normal range of motion are never fully regained

Polar Fractures

Treatment —Fractures of the upper or lower poles of the patella with displacement or comminution of the small frag ments are treated by excision of the polar fragment or fragments and reattachment of the quadriceps or patellar tendon to the remaining larger portion of the bone (Fig 418)

Comminuted Fractures of the Patella

Total patellectomy is the treatment of choice for comminuted fractures in which the patella is shattered into many fragments of varying sizes (Fig 416) Anatomical reduction of the fragments is im possible and a smooth articular surface cannot be expected

Technique of Patellectomy —In fresh comminuted fractures of the patella the joint may be approached through a vertical parapatellar or a slightly curved transverse incision The skin and subcu

taneous tissues are retracted exposing the patella and the quadriceps expansions The fragments are removed by sharp dissection with care being taken to retain all viable soft tissue The joint cavity and quadriceps pouch should be thoroughly explored, and all blood clots and fragments of cartilage and bone removed The synovia is approximated with fine plain catgut

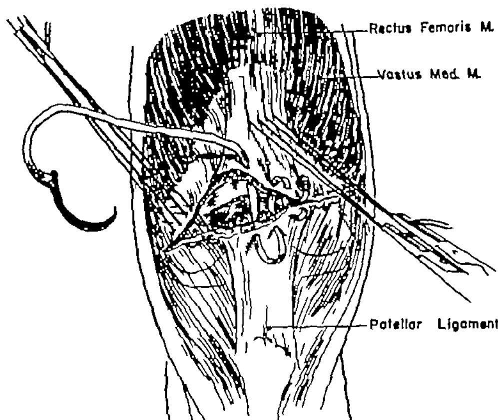


Fig 419 —Suturing in total patellectomy The tendon defect is sutured with a mattress stitch of fascia lata and heavy silk. Note the placement of the stay sutures in the quadriceps tendon to facilitate closure of the defect.

After placing interrupted sutures in the tears in the lateral expansions the quadriceps and patellar tendons are sutured to each other with fascia lata (Fig 419)

Postoperative Care.—Immobilization is established by means of a plaster cast or splint. Where the surgeon is confident of the integrity of his suture line a Hodgen splint with a Pearson attachment may be used to permit earlier active motion. Quadriceps contraction exercises are commenced as soon as the surgical reaction has subsided The remainder of the treatment is essentially the same as that outlined for fractures of the patella

Unusual Fractures of the Patella

Two other types of patellar fractures are occasionally encountered (1) fracture of the periphery of the bone i e. marginal fracture and (2) osteochondral fracture

Marginal Fractures of the Patella

A fragment may be sheared off the rim of the patella as a result of direct trauma (Fig. 420) There is little displacement and the quadriceps extensor apparatus is not damaged. Linear fractures of the periphery of the patella are easily diagnosed by proper x ray examination. A long-standing lesion must be differentiated from congenital bipartite patella, which is usually

bilateral In the bipartite and tripartite patellas the apposing surfaces are usually smooth and dense (Fig 417)

TREATMENT —Marginal fractures may



Fig 420 —Marginal fracture of patella the result of direct trauma revealed only by the skyline (tangential) view

be treated by conservative measures provided that it is possible to insure the restoration of a smooth articular surface In other cases operative removal or reduction and fixation of the fragment by suture or by screw is indicated. The exposure need not be extensive and only a small incision directly over the small fragments is necessary

Osteochondral Fracture of the Patella

Essentially this lesion is one involving the articular cartilaginous surface of the patella (see title page) It is caused by contusion of the femoral condyles by the patella Indirect violence such as a twist or a direct blow on one side of the patella may force the knee cap to move obliquely across a condyle traumatizing its articular cartilage A portion of the cartilage may be torn loose Sometimes the cartilage may be merely bruised severely In the latter case areas of degeneration resembling those seen in osteochondritis dissecans eventually develop The fracture usually occurs in childhood or adolescence The symptomatology is not unlike that of a sprain or contusion of the knee There is a history of injury followed by pain swelling and impaired function The symptoms may subside rather rapidly but the loose piece of cartilage within the joint space acts as a loose body blocking motion and even causing the joint to lock. The diagnosis is made from a study of the history from clinical manifestations and from axial roentgenograms in which any incongruity of the articular surface of the patella may be demonstrated Occasionally the diagnosis is established only after arthrotomy

TREATMENT —The patella is exposed through a median parapatellar incision the articular surfaces are inspected the loose pieces of cartilage are removed and irregularities of the cartilaginous surface are smoothed

TRAUMATIC SEPARATION OF THE DISTAL FEMORAL EPIPHYSIS

Separation of the distal femoral epiphysis is usually the result of a torsion injury or forcible hyperextension at the knee



Fig 421 —Posterior displacement of distal femoral epiphysis carrying a portion of the metaphysis

joint. The injury is seldom encountered today but its occurrence was fairly common in the day of the horse and wagon

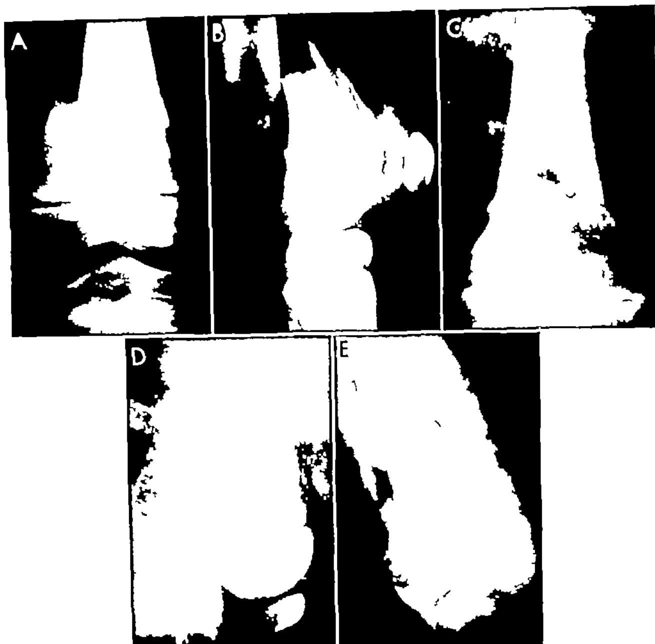


Fig 422.—Anteroposterior (A) and lateral (B) views of fracture of lower end of femur with displacement of proximal fragment into popliteal space C and D after closed reduction and application of plaster spica holding knee at 70-degrees of flexion E healing fracture after disarticulation of knee necessitated by thrombosis of popliteal artery

when youngsters in slipping off the back of a cart, caught the leg in one of the spokes of the revolving wheel

The typical displacement of the epiphysis is anterior and the fragment is tilted backward by the pull of the medial head of the gastrocnemius muscle The distal end of the femoral shaft presses dangerously close to the vital structures of the popliteal space endangering vessels and nerves In rare cases the epiphysis is displaced backward (Fig. 421) and there also may be unusual instances of lateral displacement, in which a fragment of the metaphysis accompanies the epiphysis

Treatment.—The injury calls for immediate reduction because of the potential danger to the structures of the popliteal space (Fig. 422) and reduction is carried out even if vascular impairment already exists Thrombosis of a major popliteal vessel or findings indicative of an actual

tear demand immediate operative exploration *of the popliteal space (see Chapter 40* on Blood Vessel Injuries)

The typical anterior displacement of the distal epiphysis can usually be reduced by manipulation. General anesthesia provides effective muscular relaxation If the knee joint is markedly distended it is aspirated A Kirschner wire is inserted through the proximal tibia, and strong traction is applied with the knee flexed 30–50 degrees The fragments are gently pressed back into position as the knee is further flexed to 90 degrees or more. The lateral and the *anteroposterior displacement is corrected* and the reduction is checked by roentgenograms

Immobilization is established by means of an anterior plaster splint or a casing with the knee flexed to approximately 90 degrees The fragments are stable in this position because of the pressure of the quadriceps apparatus This fixation is analogous to the triceps helping to maintain reduction of supracondylar fractures of the humerus when the elbow joint is flexed *Following reduction the circulation of the foot should be closely and repeatedly observed*

The plaster shell is removed after 3 or 4 weeks and a Hodgen splint with Pearson attachment is applied which permits gradual attainment of the extended position Protected weight bearing on crutches is permitted about 6–8 weeks after reduction and full weight bearing is allowed at 10–12 weeks

In an occasional case reduction will be unstable unless internal fixation is used Satisfactory transfixion of the fragments during the early stage of healing may be obtained by means of crossed threaded wires which apparently cause no damage to the epiphysial plate The wires are removed in 4 weeks Operative replacement is required in the unusual case in which soft tissue is interposed between the fragments or a spicule of bone is caught in muscle

Disturbances of growth are common following traumatic separation of the distal femoral epiphysis at least 25 per cent *of the children with this injury develop* angular deformity or inequality of limb length For this reason a guarded prognosis should be given and the importance of regular follow up examinations and x-ray studies should be impressed on the parents. Only by systematic follow-up during the entire period of growth is it possible to detect premature closure of the epiphysial line at an early stage If a valgus or varus deformity is developing, a stapling operation may be performed on the growing segment of the epiphysis In order to obviate *the development of unequal lengths of* the extremities when the epiphysis closes prematurely the stapling of Blount or the epiphysiodesis of Phemister may be performed on the normal extremity

FRACTURES OF THE LOWER END OF THE FEMUR (SUPRACONDYLAR)

Fractures in this region present a distinct problem in management. Not only is it difficult to overcome the displacement produced by muscle pull but vascular structures are endangered and may be damaged by the displaced fragments (Fig. 423) The concomitant injury of the quadriceps extensor apparatus often produces marked scarring and permanent limitation of the knee motion is common after this fracture

The short distal fragment of the femur is usually tilted posteriorly to almost 70 *degrees by the strong pull of the gastroc*nemius muscle which places the serrated proximal end of the femur in direct contact with or close proximity to the popliteal artery The vascular structures are sometimes severely contused or ruptured at the time of trauma and there is always the danger of further injury to the popliteal artery by injudicious emergency therapy or by forceful attempts at manipulative reduction

The proximal fragment often penetrates or severely damages the quadriceps extensor musculature particularly the vastus medialis Severe hemarthrosis may be pro-

duced with resulting synovial thickening The quadriceps may become firmly bound to the lower end of the femur and seriously limit the motion of the knee joint.

Immediate evaluation of the circulatory function of the extremity is of prime importance The absence of pulsation below the site of injury is indicative of severe placement of the traumatized segment is the only procedure which holds out hope of saving the extremity and even this operative measure has a grave prognosis (see Chapter 40 on Blood Vessel Injuries)

Supracondylar fractures are usually best managed by closed methods but open reduction is occasionally indicated where

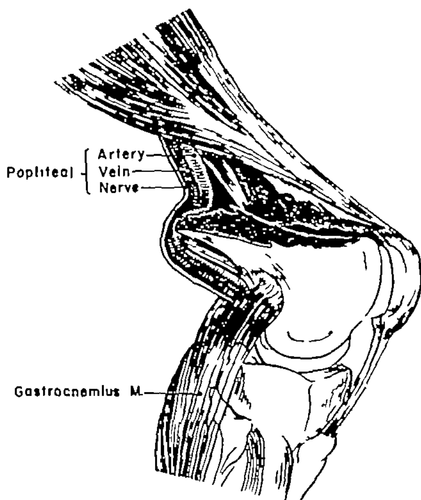


Fig 423 —Supracondylar fracture of the femur Note the proximity of the popliteal neurovascular bundle to the sharp edge of the distal fragment. The gastrocnemius muscle has flexed the free distal fragment. The proximal shaft often pierces the quadriceps tendon

contusion laceration or pressure on the popliteal artery If pulsations are absent restoration of the fragments to anatomical position is of utmost urgency Occasionally mere pressure of the bone on the popliteal artery will occlude the pulsations However if on reduction the pulsation does not return *laceration of the popliteal vessels* is probably present. In this case immediate resection suture or graft re satisfactory closed reduction has not been achieved. Malposition of the joint fragments may produce permanent impairment of knee function.

Conservative Treatment —Reduction of a supracondylar fracture can usually be achieved by manipulation supplemented by skeletal traction and the reduced fragments can then be maintained in position by skeletal traction. The Böhler Braun

frame in which the angle is behind the fracture and not at the knee joint is one of the most efficient forms of apparatus for postreduction support

Technique —Reduction is accomplished as follows General anesthesia is administered and the joint if distended is aspirated A Kirschner wire is inserted at the tibial tubercle and a spreader attached. Continuous traction is maintained throughout the manipulation At first the pull is exerted in line with the deformity An assistant provides gentle continuous counter traction on the midposterior thigh while the hip is flexed at approximately 25 degrees Sufficient traction is established to restore the length of the femur The surgeon gently manipulates the distal fragment into position with the proximal fragment at the same time correcting any valgus varus or rotational deformity of the lower fragment Extreme caution must be exercised throughout the procedure because of the danger of traumatizing the popliteal artery Once reduction has been achieved traction is decreased to allow impaction The position of the fragments is then maintained by placing the extremity in the corrected position on a Böhler Braun frame (Fig 425 *A*) or Hodgen splint with a fixed Pearson attachment (Fig 425 *B*) A firm rolled flannel bandage is placed just proximal to the fracture site and the limb is so adjusted on the splint that the angle of the frame lies at the level of the fracture The position is checked by roentgenograms and maintained by traction of 10–14 pounds in the average adult (Figs 426 427)

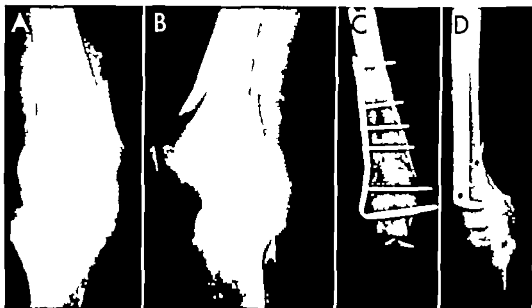


Fig 424 —Anteroposterior (A) and lateral (B) views of supracondylar fracture C and D treated with angulated blade and screw fixation Note that the blade is bent to match the normal flare of the lateral condyle Early knee motion is permitted

Postreduction Care —Roentgenograms should be taken every 2–4 days during the first 2 weeks and at regular intervals thereafter until there is no longer danger of displacement of the fragments The soft tissues of the posterior thigh as well as the circulatory and neurological status of the extremity should be frequently checked to make certain that complications are not developing. The apparatus is inspected twice daily and is readjusted as necessary After the acute symptoms subside quadriceps setting without joint motion should be permitted The maintenance of reduction during the first 3 weeks is often facilitated by increasing the anterior bow at the fracture site At the end of the

A

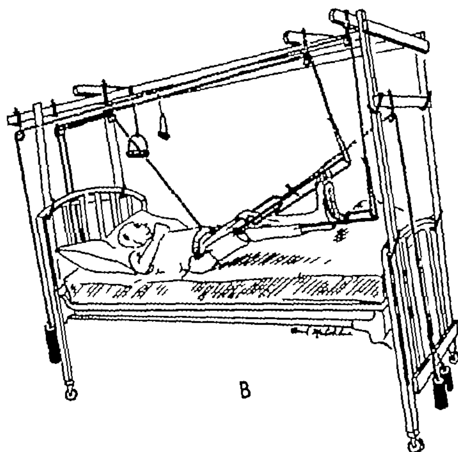


Fig 423 —A, Bohler-Braun frame for immobilizing supracondylar fractures of the femur Note the position of the sandbag proximal to the fracture line B Hodgen splint with Pearson attachment

third week when the fragments are beginning to consolidate the anterior bow may be restored to normal by carefully reducing the degree of knee flexion

In the usual supracondylar fracture healing has progressed sufficiently by 6 weeks to permit decreasing the amount of knee flexion and beginning the quadriceps exercises with a little joint motion. Accordingly the Kirschner wire is removed and the extremity placed in suspension. Extension at the knee is gradually achieved and active exercises of the quadriceps are performed under supervision When a good range of extension is possible and the roentgenograms show the fragments to be firmly united which is usually at the end of the eighth or tenth week after injury partial weight bearing is permitted with crutches Active exercises are continued during this stage of convalescence At the end of 12 weeks consolidation of the fragments is as a rule complete and quadriceps power has recovered enough to control motion of the knee joint At that time increased weight bearing may be permitted and the crutches gradually eliminated

Operative Treatment —Open reduction of supracondylar fractures is seldom advisable except in a few carefully selected cases in which it is desirable to reduce the period of incapacity to the minimum or in which closed reduction is unsatisfactory The general condition of the patient must be satisfactory (Fig 428) and the fracture must show little comminution if open reduction and internal fixation of the fragments are to be undertaken.

Technique —The fracture may be exposed and reduced through a posterolateral incision in which the vastus lateralis is retracted anteriorly In some instances both medial and lateral incisions are used. Several types of internal fixation are available (Figs 424 430 431) Two Rush nails are suitable for some cases (Fig 429) One nail is passed through the cortex of the medial condyle which is exposed through a small incision retracting the vastus medialis muscle anteriorly The second nail is passed through the lateral condyle The nails are tapped in alternately so that they progress proximally at about the same rate and they are guided across the fracture site and well up into the femoral shaft. Although reduction may be maintained by this method the fragments are not necessarily fixed rigidly The use of a slotted plate applied in the conventional manner often gives more satisfactory fixation However care must be taken to bend the plate to fit the contour of the distal frag



Fig 426 —Anteroposterior (A) and lateral (B) views of supracondylar T fracture of femur Treatment consisted of closed reduction and traction. C and D 1 year later slight valgus position persisting but excellent function present.

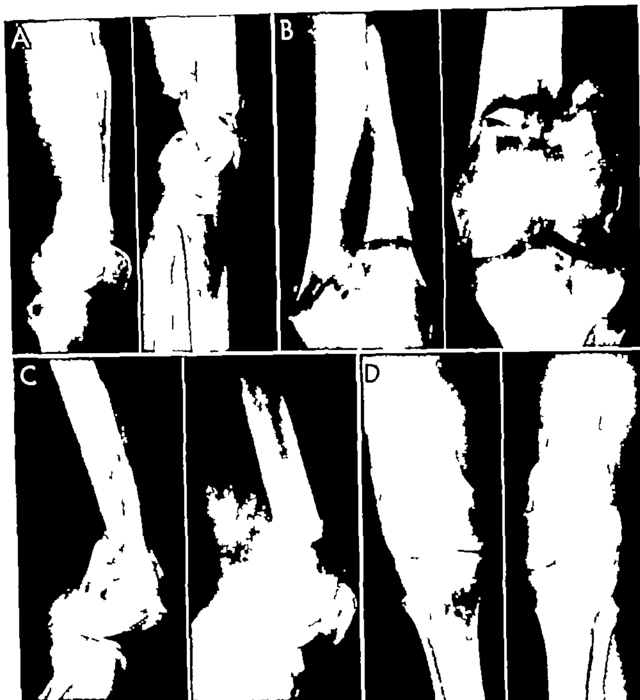


Fig 427 —Lateral (A) and anteroposterior (B) views of both femora showing extensively comminuted fractures sustained in automobile accident Treated by closed reduction and traction C and D same femora 1 year later Motions were left, 5 degrees fixed flexion further flexion 75 degrees right complete extension flexion 85 degrees



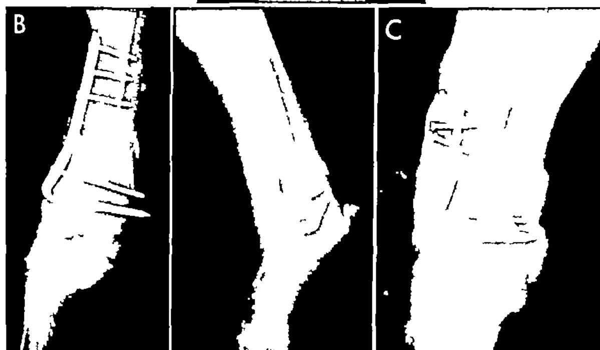


Fig 428 —A lateral view of supracondylar fracture Treated by early open reduction and internal fixation with plate and screw B postoperative views showing fixation material C showing failure of internal fixation which did not hold because of porosity of bone The situation *was complicated by severe pernicious anemia and poor nutritional state Closed reduction* and skeletal traction would have been more satisfactory

ment If there is a T fracture the condyles may be held together by a bolt which replaces the distal screw in the plate Some authors feel that a blade plate with screws is a satisfactory means of immobilization and it has the advantage of permitting gentle exercise of the quadriceps to be performed early *Following operative reduc*

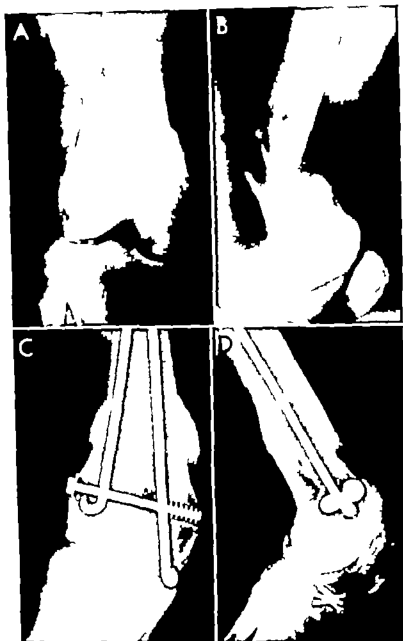


Fig 429 —Anteroposterior (A) and lateral (B) views of comminuted supracondylar T fracture of femur C and D treated by open reduction and fixation with two Rush nails The lag screw converts a T fracture to a supracondylar fracture by fixing the condyles

achieves the most satisfactory fixation (Fig 424)

Postoperative Treatment —The choice of postoperative management depends to a great extent on the surgeon s opinion of the stability of the reduction A Hodgen splint with a Pearson attachment

tion just as after conservative handling the circulatory and neurological status of the extremity and the soft tissues of the posterior thigh should be under close observation Crutch walking with increasing weight bearing may be permitted when joint motion muscle strength and union

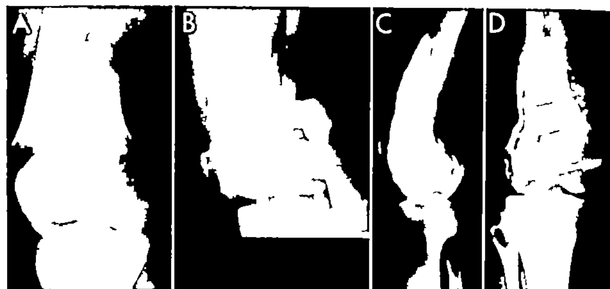


Fig 430 —T fracture treated with a lag screw and two stainless steel screws Anteroposterior view (A) and lateral view (B) showing markedly displaced fractures. Lateral view (C) and anteroposterior view (D) after open reduction and screw fixation of fractures The lag screw stabilizes the condyles



Fig 431 —Left fracture of lateral femoral condyle Right treated by internal fixation Early motion without weight bearing is thereby possible.

of the fracture have progressed to the point where such physiologic activity will be beneficial

DISLOCATION OF THE KNEE JOINT

Traumatic dislocation of the knee joint is a rare lesion which is produced by great force either directly or indirectly applied The tibia with respect to the femur may be dislocated backward forward or to either side and may be rotated (Fig 432) The dislocation may be complete or incomplete Concomitant damage of the surrounding structures is usually extensive In complete dislocations both the cruciate and the collateral ligaments are ruptured and the capsule is torn and accompanying fracture of the tibial spine or condyles or of the femoral condyles is not uncommon. Nerve and vascular complications are often present the lateral popliteal nerve may be stretched and the popliteal vessels damaged

Diagnosis of a dislocation of the knee presents little difficulty The nerve complication is evident from the motor and sensory disturbance and the circulatory disruption from the absence of pulsation and the extreme swelling which rapidly develops. Except in the case of the posterior dislocation in which the pressure on the popliteal artery precludes any delay in treatment an x ray film is made to con

manipulation it is usually due to the interposition of soft tissue between the articulating surfaces in which case operative intervention is required Failure to achieve reduction of lateral dislocation may also be caused by displacement of the medial hamstrings into the intercondylar notch In the latter condition closed reduction may succeed if knee is flexed to a right angle and traction and manipulation applied

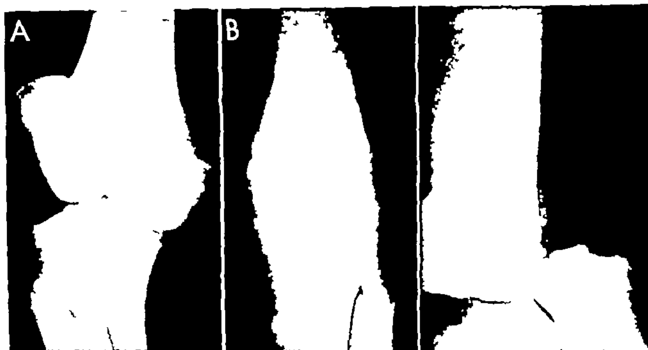


Fig 432.—A, rotatory dislocation of knee Closed reduction restored peripheral circulation B anteroposterior and lateral views of posterior dislocation of the knee sustained when patient hit a tree while skiing at a high rate of speed. *Vascular damage* of the popliteal space was so severe that in spite of a prompt reduction of the dislocation gangrene of the foot and leg developed and supracondylar amputation was necessary

firm the diagnosis and to verify the existence of fractures.

TREATMENT —A posterior dislocation must be reduced immediately—even without administering an anesthetic agent if necessary—to relieve the pressure on the popliteal artery The other types of dislocations should be reduced as soon as possible after the injury

As a rule reduction may be obtained by applying traction and countertraction and pressing the tibia into normal relation to the femur General anesthesia is used If difficulty is experienced in reducing a medial or lateral dislocation by means of

AFTER TREATMENT —The joint is aspirated and then immobilized in a bivalved plaster cylinder with the knee flexed slightly Careful watch of the circulatory status is imperative Immobilization may be discontinued in 6–8 weeks from the time of injury Intensive quadriceps exercises should be performed throughout the period of treatment, and crutches are used until full quadriceps power has returned In the case of associated ruptures of the popliteal artery immediate repair of the vascular injury is necessary Saphenous vein or artery grafting may save the extremity but on the whole the prognosis is

have consolidated mobilization exercises are started

OPERATIVE TREATMENT —Open reduction is occasionally indicated when closed reduction fails to achieve a satisfactory anatomical restoration of the joint line The incision is made on either side of the patella the capsule is opened and blood clots are removed from the joint The menisci are excised if damaged Traction is applied and the depressed fragments are elevated into position manual compression being used if necessary A transfixion bolt or lag screws are then passed parallel to the articular surface and traversing the entire width of the condylar region. Light traction is maintained with the extremity on a Hodgen splint with a Pearson attachment or a cast is applied depending on the stability achieved

Postoperative care is similar to that described for the treatment of the single condylar fractures

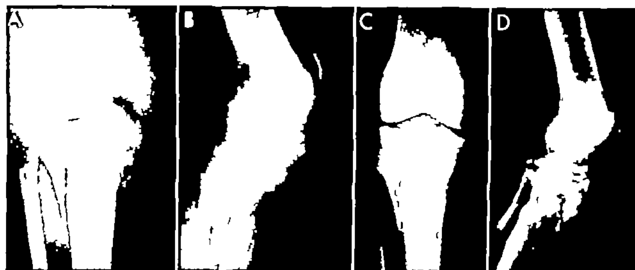


Fig 436 —Anteroposterior (A) and lateral (B) views of comminuted fracture of both tibial plateaus C and D 1 year after treatment with manipulation and traction

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28  Fractures of the Tibia and Fibula

FRACTURES OF THE tibia and fibula occur in all age groups approximately equally distributed between the two sexes Many of these fractures are easily treated others particularly the open comminuted fractures of both bones pose extreme difficulties in management

About one third of these fractures are caused by direct violence the rest by falls or twisting injuries Experience at the Fracture Clinic of the Massachusetts General Hospital shows that the automobile produces the majority of the serious tibial fractures The bumper of a speeding car which strikes the leg of a pedestrian produces multiple fractures and often drives sharp bone fragments through the skin Often the damage is multiplied as the victim is dragged along the street or is crushed by the over riding tire

EMERGENCY SPLINTING

The most efficient comfortable and easily applied emergency splint for injuries of the ankle leg and knee is the well known pillow and-sides splint (p 574 Fig. 454) Clothing such as sweaters coats etc may be used if a pillow is not available Wounds should be covered with a clean dressing The limb is carefully supported and deformities gently corrected by manual traction on the foot while the splint is being applied. The patient should then be transported quickly and carefully preferably by ambulance to the nearest hospital that has the equipment and the staff to care for all types of major injuries Correct early definitive treatment is essential Delay may be disastrous

CLINICAL AND X-RAY EXAMINATION

The severely injured patient with a fracture of the leg requires accurate evaluation of his general condition and of the local injury The general management of patients with severe injuries is discussed in Chapter 9 on Early Examination and Treatment of the Injured Patient The program outlined in Table 1 on page 95 of that chapter should be carefully followed Correct management of the leg injury depends on properly weighing many factors which will be elicited from the history the physical examination and a study of the x rays For obvious reasons including medicolegal ones the information obtained should be promptly and accurately noted in the patient s record

Among the variables which are particu

larly important in the management of fractures involving the shafts of the tibia and fibula are the following age mechanism and severity of injury local examination and x ray examination

Age

Infants and growing children have such marvelous powers of repair and remodeling of bone that simple nonoperative treatment of their closed leg fractures almost always produces excellent results For adults equally good results are often difficult and sometimes impossible to attain The surgeon must be familiar with various techniques of management. Operative treatment of certain fractures of the leg in adults is sometimes necessary and often advisable

Mechanism and Severity of Injury

Tissue damage is proportional to the force applied Fractures due to a slowly applied indirect force—for example the fractures that result from skiing injuries and minor falls are accompanied by minimal cellular damage to the bone and the soft tissues The union of such fractures if properly treated is rapid and an $A_1E_1F_1$ (p 9 Fig 2) result should be obtained

Fractures caused by a more severe force such as a fall from a considerable height a blow from the bumper of a speeding automobile a crushing injury or a high velocity rifle bullet, call for a guarded prognosis Hemorrhage edema, and soft tissue necrosis in the presence of large wounds contaminated with bits of clothing and dirt from the street make infection a frequent complication. Delayed union is the rule and nonunion is frequent in these cases The end result is seldom perfect shortening and malalignment are common Frequently soft tissue fibrosis causes circulatory and motor impairment In the most severely injured legs an ischemic paralysis of the calf and foot muscles may produce a rigid anesthetic clawfoot the deformity of the foot showing a striking similarity to Volkmann s ischemic paralysis of the hand (Fig 437) Occasionally in spite of the most expert care amputation may prove to be the only satisfactory solution to such problems

Local Examination

In the course of the local examination of the acute injury to the leg the foot should be watched for sensory motor and circulatory changes Paralysis of the dorsi flexors and evertors of the foot, due to injury of the peroneal nerve at the proximal fibula although rare should not be overlooked

Angular deformity and displacement of the tibia are noted by inspection and gentle palpation of the subcutaneous surface of the tibia. Rotatory deformity is difficult to detect by x ray but its presence or absence is easily determined clinically by inspecting both legs with the thighs in neutral position, the patellae facing upward The foot and ankle are normally in slight external rotation (5–15 degrees) in relation to the femur and proximal tibia (Fig 438)

The intact skin of a closed fracture is almost perfect insurance against development of local infection, but pressure marks and extensive skin discoloration point to severe underlying soft tissue damage The size and location of soft tissue wounds should be noted carefully A wound that communicates with an underlying fracture is the open door to infection and the surgeon must choose promptly the safest way of closing the door In the case of a minute puncture wound caused by a pointed bone fragment piercing the skin beneath reasonably clean protective clothing it is unlikely that pathogenic organisms have been introduced into the deeper tissues and such patients may properly be treated conservatively by mechanically cleansing the skin applying a sterile dressing to the wound using antibiotics systemically and treating the fracture as though it were a closed one Repeated daily inspection of the

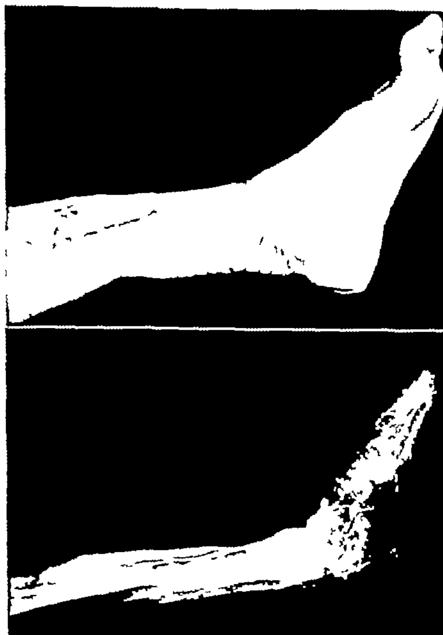


Fig 437 —A severe crushing injury to the leg caused comminuted fractures of the tibia and fibula, which healed satisfactorily but with marked impairment of function of the foot and ankle There was cavus and equinovarus deformity with clawing of the toes also, marked fibrosis of the soft tissues involved muscles nerves, and blood vessels The leg was amputated 3 years after injury Top clinical appearance just before amputation Bottom, arteriogram of the amputation specimen showing deficient blood supply from partially obliterated anterior and posterior tibial arteries.

wound will insure that the rare case in which local sepsis develops will be detected early and treated promptly

The open fracture with a skin wound larger than a puncture of more than 1–2 mm in size requires surgery to convert it into a closed fracture

X ray Examination

The final step in the evaluation of the injury is a study of adequate x ray films Before transporting the patient to the x ray room the wounds should be covered with a sterile dressing and the pillow splint rebandaged to the limb avoiding the use of safety pins or other metallic objects which would obscure the x ray view Two-plane anteroposterior and lateral x rays should be taken with the splint in place The films should include the whole shaft of the tibia and fibula as well as the knee and ankle joints After inspection of these films additional views should be obtained if necessary In studying the x rays special attention should be given to a number of factors such as bone structure location and type of fracture bone displacement and the stability of the fracture

Bone Structure.—Abnormality of size shape mineralization or trabecular pattern of the tibia suggests that the fracture may be a pathological one such as occurs in fragilitas ossium osteitis deformans bone cyst or bone tumor

Location of Fracture. — Fractures near the end of the tibia involve much cancellous bone and tend to heal promptly The middle half of the tibia is chiefly composed of compact, poorly vascularized cortical bone containing relatively few living cells Fractures in this region heal more slowly than those at the bone ends where there are more osteocytes and greater vascularity

Type of Fracture.—Fractures with only two fragments have a better medullary blood supply and a more rapid rate of healing than do comminuted fractures Long oblique fractures produce surfaces of large area, which tend to heal more rapidly than do transverse fractures A free cortical fragment which lies transversely in the fracture line is a sure omen of delayed union, because it must be completely absorbed and retrabeculated before sound healing is obtained (Fig 439)

Displacement —The separation of fracture surfaces always delays healing



Fig 438 —Fracture of both bones of leg as seen immediately after injury Note the external rotation deformity which must be corrected at the time of fracture reduction.

Marked separation particularly if one of the fragments is angulated posteriorly or laterally suggests that soft tissue (muscle) is interposed and in such cases manual reduction is unlikely to be successful Hair line apposition of the fractured surfaces promotes optimal healing in minimal time

Angular and rotational displacement of two-fragment tibial fractures is easily corrected but the angulation which occurs in the intermediate fragments of comminuted fractures is difficult to correct by closed manipulation As noted above the x ray film is less reliable in the diagnosis of ro-

tational deformity than is clinical obser vation

Shortening of the extremity due to over riding of the fractured bone ends requires recognition and careful estimation of its prognostic significance In some instances it is unnecessary or even unwise to at tempt to restore full length In the child 1 cm or less of over riding is acceptable and will be corrected by accelerated growth of the tibia. Although uncorrected over riding of the bone ends in the adult patient results in permanent shortening of the limb the healing process is accelerated because of no treatment for the over riding and the fracture unites with surprising rapidity In certain severely comminuted fractures in adults shortening of as much as 2 cm may be preferable to the extreme delay in union which occurs if an attempt is made to maintain full length (Fig 440)



Fig 439 —A severely comminuted closed fracture of tibia and fibula before reduction. Note the marked comminution and displacement of small bone fragments There is a 90-degree ex ternal rotation deformity the proximal tibia is seen as an anteroposterior projection the ankle as a lateral projection. B after closed reduction The general alignment is satisfactory but there is still marked displacement of the smaller intermediate bone fragments Delay in union is to be expected regardless of the type of treatment. C 6 months after injury union not yet complete The two avascular cortical fragments noted in the fracture line (*arrows*) have contributed to the delay in bone healing D 26 months after injury union finally complete

Stability —In selecting a satisfactory method of treatment, it is helpful to clas sify the fractures of the tibia and fibula as stable or unstable. Figure 441 shows some examples of stable and unstable fractures.

Fractures of the fibula alone are very stable they need minimal immobilization and show no tendency toward increased displacement during convalescence Frac tures of the tibia which have not been displaced either by the original injury or

in transportation are in general reasonably stable and satisfactory position can usually be maintained in a plaster casing Although the bone ends of fractures which are displaced have lost the support of intact periosteum they are not necessarily oblique fracture of the tibia in the adult is an unstable fracture which usually redisplaces promptly after reduction unless some form of internal fixation is used The comminuted fracture with a displaced "butterfly" fragment is difficult to reduce



Fig 440 —A, comminuted segmental open fracture of tibia and fibula immediately after injury Note that the distal fracture shows minimal displacement and is relatively stable The proximal fracture is comminuted displaced and unstable B 19 days after closed reduction and skeletal traction to maintain length and alignment Distraction has occurred at the proximal fracture line and delay in union may be predicted. C 3 months after injury The distal fracture is healing satisfactorily but there is delay in healing of the proximal fracture Note the cortical fragments not yet revascularized The clinical and x ray evidence of delay in union prompted the use of autogenous iliac onlay grafts D 10 months after injury 7 months after bone grafting union satisfactory Excellent end-result $A_1E_1F_1$

unstable If the fracture line is transverse and if satisfactory apposition of the bone ends can be obtained by manipulation, redisplacement is unlikely to occur and such fractures are classified as relatively stable

Unstable fractures are those in which displacement tends to recur and in which adequate reduction cannot be maintained in a plaster casing The displaced spiral or by manipulation and is also unstable after reduction.

TREATMENT

General Considerations

If the factors noted above have been properly evaluated the treatment suited to the individual case can be selected with

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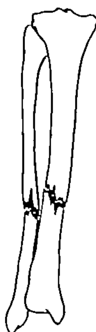
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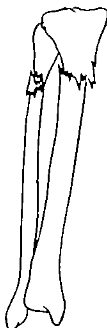
TREATMENT

General Considerations

If the factors noted above have been properly evaluated the treatment suited to the individual case can be selected with

STABLE FRACTURES







UNSTABLE FRACTURES





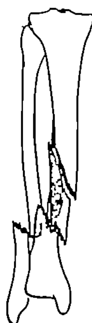




Fig 441 —Some examples of relatively stable and relatively unstable fractures of tibia and fibula

some confidence that it will succeed in producing a good result Good results can be expected if (1) soft tissue wounds are promptly closed (2) bone apposition and alignment are satisfactory and (3) the concerning fracture healing can be obtained Progressive narrowing of the fracture line and decreased density of the bone ends on either side of the fracture are indications that the normal physiological



Fig 442.—A, comminuted unstable closed fracture immediately after injury Treated by open reduction and plate fixation B Immediately after open reduction and fixation with a slotted plate Union was solid in 3 months C 1 year after injury Note the small amount of callus formed after anatomical reduction and internal fixation. Excellent end-result: $A_1E_1F_4$

fracture is immobilized until union is complete

The surgeon must be familiar with the clinical and x ray signs of incomplete union and must continue immobilization until these signs have disappeared Clinically incomplete union is suggested by the presence of local increased temperature tenderness on percussion or palpation of the fracture site and pain or demonstrable motion on application of gentle manipulative force By a careful study of x ray films a great deal of information processes of healing are at work. Persistence of cortical density or increased bone density at the fracture line means delayed fracture repair Additional information can be obtained by the observation of the fracture callus Only small callus masses are found following open reduction and internal fixation (Figs 442 and 443) Large callus masses suggest that immobilization may be inadequate In delayed or nonunion of the tibia large callus buttresses are often formed Re-establishment of a normal trabecular pattern which



Fig 443 —A open comminuted fracture of both tibia and fibula immediately after injury B after debridement and plating. Note the defect in the fracture line indicating loss of a bone fragment. Unprotected weight bearing was started 7 months after injury and at 1 year the result was rated excellent. C, 21 months after injury The plate has broken nonunion is present, and there is massive excess callus. At a second operation the plate and the excess callus were removed the bone ends were freshened autogenous iliac onlay grafts (Phemister) were applied and the fracture was immobilized by a Lottes nail. D 5 months later Clinically and by x ray examination healing appeared to be progressing satisfactorily Patient was on full activity

crosses the fracture line and re-establishment of the medullary canal are the last roentgenological signs of union to appear

Fractures of the Fibula

Fractures of the shaft of the fibula are stable and heal readily when there is no associated fracture of the tibia. Immobilization of the leg in a short walking boot for about 4 weeks is usually sufficient treatment Crutches may be necessary for the first week or two but thereafter full weight bearing in the casing should be encouraged Fractures of the fibula that are associated with tibial fracture almost always come into satisfactory alignment when the tibial fracture is reduced The treatment of such fractures is therefore treatment of the tibial fracture

Fractures of Both Fibula and Tibia

Closed Fractures in Children

Fracture of both the tibia and fibula in children is considered separately because little of what is said with regard to adults pertains to children The problems of slow

healing and of permanent disability caused by malunion of displaced fractures do not occur in children For these reasons open reduction of fractures of both bones of the leg in children is rarely necessary This reveal angular deformity remanipulation can safely be delayed for 7–10 days This delay will allow correction of the angulation without losing the apposition obtained initially The long leg plaster casing can



Fig. 444 —A short oblique fracture of tibia with only fair approximation of bone ends in a boy aged 5 view taken immediately after injury In an adult this fracture might slip in plaster and union would certainly be delayed but in a 5-year-old child an excellent end-result can easily be obtained by nonoperative means B in plaster after closed reduction alignment is good The partial apposition which is present is acceptable in a child of this age C 1 year after injury end-result: $A_1E_1F_1$

generalization is based on experience in the Fracture Clinic of the Massachusetts General Hospital and is amply confirmed by the experience of other surgeons Meticulous care should be taken in correcting alignment Rotational deformities do not correct themselves Minimal apposition is acceptable but as in adults accurate alignment is essential (Fig 444) Initial treatment includes manipulation under anesthesia if necessary and application of a long leg plaster casing If check-up x rays usually be removed at 6 weeks The use of crutches for another 2 weeks is usually sufficient for solid union

Closed Fractures in Adults

For the treatment of closed fractures in adults a number of methods are available No single method is universally applicable for each has its indications its failures as well as its successes and its contraindications

Closed stable minimally displaced fractures of the tibia, which occur commonly in children and occasionally in adults are best treated by the application of a toe-to-groin plaster casing with the foot in neutral position and the knee flexed at 20 degrees In the average case union is strong enough in 6 weeks to allow partial weight bearing with crutches and a long casing with a walking heel Solid union is usually present in 8–10 weeks after injury

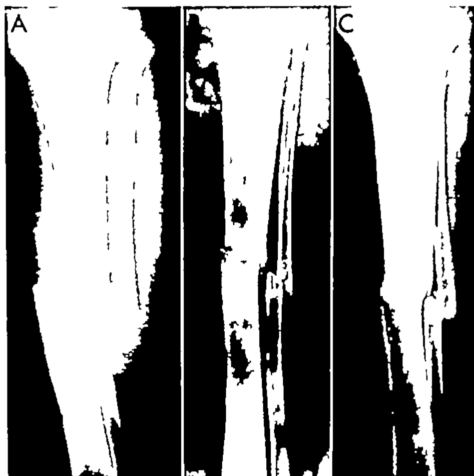


Fig 445 —A open transverse fracture of both tibia and fibula at time of injury Treated by debridement of wound manipulation and immobilization in a plaster cast without internal fixation with excellent result. B 10 weeks after injury C at 14 months result satisfactory Flexion of the knee was limited to 90 degrees

Certain closed displaced fractures of the tibia may be reduced by manipulation and converted to stable fractures which are then treated by immobilization in a carefully applied plaster casing (Fig 445)

Technique of Manipulation —Minor angular and rotatory deformities can sometimes be corrected manually without the use of anesthesia but in most instances full general anesthesia is necessary There is much less chance of redisplacing the fracture during the application of the plaster if the services of two skilled assistants are available during the manipulation and application of the plaster The manipulation should be attempted promptly for hemorrhage and edema produce so much swelling of the leg that delayed manipulation is more likely to fail

A simple and usually satisfactory manipulative technique is illustrated in Figure 446 With the knee flexed to a right angle over the end of the operating table axial traction is applied manually or by attaching weights (10–30 pounds) to a simple padded ankle hitch or to a Kirschner wire (Fig 446 *top*) When full limb

length has been restored the traction force is reduced to about 5 pounds and by manipulation the remaining fracture displacement is corrected The surgeon then aligns the knee and foot to correct the rotational deformity During the manipulation he repeatedly compares the fractured ber over two or three layers of sheet wadding When this section of the plaster has hardened the knee is gently straightened and while an assistant holds the boot with the foot in the normal amount of external rotation the surgeon supports the thigh with the knee flexed at 20 degrees and the

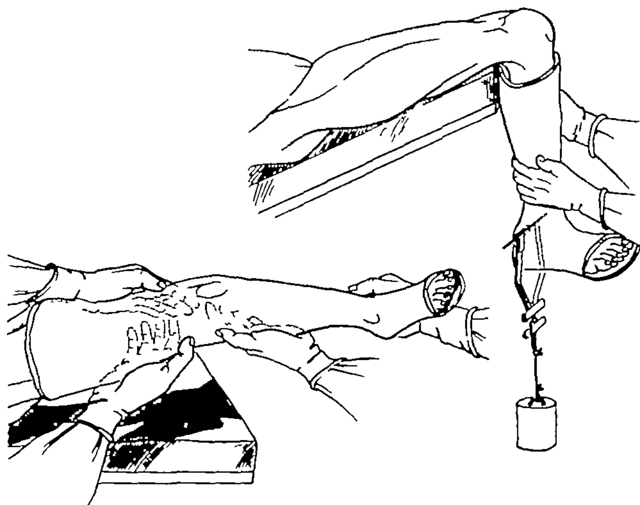


Fig 446 —**Top** simple method for reduction of tibial shaft fractures by closed manipulation while temporary traction is applied The wire is removed after the plaster has hardened **Bottom** plaster casing extended well up on the thigh. Note that the knee is semiflexed (at 20 degrees) and that the rotational alignment is correct.

extremity with its normal fellow When the surgeon is satisfied both by palpation and by visual inspection that he has obtained the best possible alignment the traction is removed the foot is gently brought to a right angle and while the surgeon carefully steadies the limb a plaster casing is applied in two sections A boot is first applied from the toes to the tibial tubercle Most surgeons prefer to pad the bony prominences with felt or sponge rub-

patella pointing upward This insures proper alignment of the knee and ankle (Fig 446 *bottom*) Another assistant then applies the second section of the plaster When complete the plaster extends from the toes to the groin with the knee in 20-degree flexion and the foot at a right angle Two-plane postreduction x ray films are made Minor residual deformities can easily be taken care of at the time of the first plaster change which is made 2–3

weeks after reduction At that time a new snug fitting toe-to-groin plaster casing is applied and the position and alignment of the fracture are checked clinically and by x ray films

It should not be expected that displaced tibial fractures in adults will heal firmly bearing in a well fitted long leg walking plaster casing in the final few weeks of the healing process

Certain comminuted fractures of the tibia are better suited to closed methods of treatment than to open reduction and fixa tion (Fig 447) Union in these cases is



Fig 447 —A, comminuted segmental fracture of tibia and fibula before reduction This type of fracture is unstable and may redisplace after closed reduction even if immobilized in a snug plaster casing Postmanipulation alignment may be maintained by skeletal traction. The traction should not be too heavy or distraction and delayed union will result Within 7–14 days the fracture will usually be stable enough to permit discontinuing traction and immobilization in plaster B after reduction with skeletal traction through os calcis The leg was placed in a plaster casing and the wire removed 19 days after injury C at 1 year fracture well healed This type of comminuted segmental fracture should be treated by closed reduction

in less than 12 weeks many of them will require up to 6 months before they are solidly united Immobilization should be continuous until there are clinical and x ray signs of firm union. Inadequate fixa tion or its premature discontinuance leads to bone absorption and nonunion At the Massachusetts General Hospital it is gen eral practice to allow protected weight always slow and may be further delayed by operative treatment Careful manipula tion to obtain alignment of the joint sur faces of the knee and ankle and immobili zation in a well fitted long plaster casing is often the best and safest method of treatment of such fractures. If the fracture is unstable position may be obtained by skeletal traction which should be con-

tinued for 1–3 weeks and then a plaster applied

FRACTURES OF THE TIBIA

No single technique for the reduction of tibial fractures has definitely been ac knowledged as superior but there are requirements that should be fulfilled no mat ter what operative method is used These requirements are

1 Rigid aseptic technique is essential for infection is disastrous
2. Accurate anatomical reduction should be obtained
3 The fixation methods used should hold the fracture securely preventing rotatory and angular displacement.
4 Impaction of the fractured surfaces should be encouraged
5 The operative exposure and the fixa tion materials should interfere minimally with the blood supply to the fractured bone ends

Closed Fractures of the Tibia

OPERATIVE TREATMENT —Several general features with regard to the operative technique of closed fractures should be mentioned The most suitable time for sur gery is early before the swelling has progressed to the extent of blister formation but operation should not be undertaken until preoperative evaluation is complete and shock has been treated Adequate an esthesia and proper assistance must be available

If these conditions cannot be obtained the fracture should be treated by a closed reduction General anesthesia is most com monly used Careful shaving cleansing with soap and water and sterile prepara tion of the skin precede the open reduction. The approach to the tibia may be made by a curved incision the central portion of which lies over the tibial crest Sufficient length is necessary to allow adequate ex posure The skin flaps must be elevated sufficiently to expose the medial border of the tibia. The saphenous nerve and vein should be protected The proximal end of the incision may be carried across the ten dons of the sartorius gracilis and semi tendinosus muscles Distally the anterior tibial tendon is reflected laterally with the periosteum The fracture is exposed with a minimum of periosteal dissection Soft tissue and hematoma are removed from between the bone ends Reduction is then accomplished under direct vision applying traction and rotation as necessary The surgeon should strive to obtain an ana tomical reduction Fixation devices which may be used include conventional plates and screws slotted plates and screws Par ham bands wires screws and intramedul lary nails The preferences of the fracture staff at the Massachusetts General Hospital are indicated below

Long spiral or *oblique two-fragment fractures* of the tibia in adults are notably unstable and adequate reduction is diffi cult to obtain and still more difficult to maintain by closed methods Such cases are best treated by open reduction and screw fixation (Fig. 448)

The fracture is exposed through a curved incision limiting the dissection as much as possible in order to avoid stripping of periosteum and muscles from the bone The fractured surfaces are opened by externally rotating the foot and ankle while holding the proximal fragment in a neutral position. The blood clot is removed and the fractured surfaces are carefully inspected. Shortening is overcome by trac tion on the ankle either manually or through a Kirschner wire in the os calcis The surgeon selects suitable sites for in troduction of the screws notes the direc tion the screws will take and then reduces the fracture The reduction should be ana tomically perfect and it is maintained by a bone clamp while the screws are in serted. Fixation is most secure if the screws are inserted at a right angle to the plate and to the long axis of the tibia. The holes in the nearer cortex are made with a drill which has the same diameter as the outside diameter of the screws (9/64 inch) (p 655 Fig 524) The distal cortex is

drilled with a 7/64-inch drill Thus when the screws are tightened they produce compression at the fracture site Spiral fractures treated in this manner heal promptly in anatomical position Single screw fixation is insecure but 2 screws may be sufficient for firm fixation. If the fracture line is so nearly transverse that 2 screws cannot be inserted, a slotted plate is used The leg is immobilized in a long plaster casing 8–10 weeks and a walking screws. Fresh open, as well as closed fractures may be successfully treated by this method The slotted plate may permit impaction of the fractured surfaces and it may be superior to the conventional type *

A slotted plate of proper size is selected so that 2 or 3 screws may be inserted on either side of the fracture line The plate may be placed either on the medial or on the lateral surface of the tibia. A Lambotte or Lowman clamp is applied to

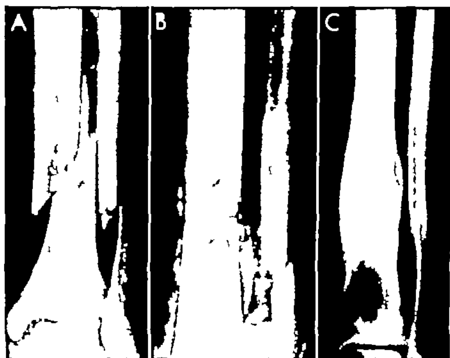


Fig 448 —A spiral oblique fracture of tibia 3 days after manipulation and application of plaster position unsatisfactory This type of fracture is unstable and internal fixation is usually indicated Screw fixation is a very satisfactory method of treatment. B after open reduction and screw fixation. Iliac grafts were placed about the fracture site C 1 year later end-result excellent Excess callus is present due to bone grafts

heel is used for an additional 2 weeks in most cases

Short oblique and *transverse fractures* of the tibia which are unstable may be treated by various methods The surgeon should select a technique in which he is experienced Two accepted alternative methods of fixation are (*a*) the application of a plate and screws and (*b*) introduction of an intramedullary nail.

A very satisfactory method of treatment of selected unstable tibial fractures is open reduction and fixation with a plate and fix the fractured fragments and hold the plate A centering device should be used for the drilling of the proximal screw holes this will allow perfect centering of the screws in the slot. The screws should be long enough to penetrate both cortices.

INTRAMEDULLARY NAILING —Intramedullary nailing which insures reasonably firm fixation of the tibial fracture and permits early weight bearing has become

* The superiority of the slotted plate over the conventional type is questioned by many members of the Massachusetts General Hospital Fracture Clinic

popular in recent years chiefly because of the work of Lottes who has developed a specially designed nail and has improved the technique for its insertion This method has been used at the Massachusetts General Hospital Fracture Clinic on a limited number of cases with results that indicate its further trial Its potential disadvantages seem to be (1) the rather difficult and complicated technique of insertion of the nail (2) interference with intramedullary blood supply and consequent delay in healing of the fracture and (3) difficulty in removing the nail

The indications for the use of the method and the technique are described by Lottes* as follows

FRACTURES SUITABLE FOR NAILING

1 Any fracture in the middle one-third or upper portion of the lower one-third of the shaft of the tibia is suitable for nailing This would include oblique and comminuted fractures with the transverse or short oblique fractures being most suitable In the lower one-third fractures the fracture line should not extend beyond a point 3 in (7 6 cm.) from the ankle joint. Fractures lower than this can be nailed, but, like those in the upper one-third fixation is not as secure because of the width of the canal

2 Multiple segmental fractures that is double or triple fractures at any level can be nailed since one is always in the mid one-third of the shaft. During nailing of the upper one-third fractures the distal fragment must be displaced so that about one-half the width of the shaft of the distal fragment is posterior to the proximal fragment. If this is not done the nail will emerge through the proximal fracture site during nailing and pass posteriorly to the distal fragment After the nailing has been completed the displacement tends to correct itself owing to the bend of the nail in its proximal portion if displacement does not correct itself during nailing it can be done manually while the traction is still on

3 Single fractures of the upper one-third and those occurring in the distal 3 in of the shaft can be nailed however fixation is not so complete owing to the width of the medullar canal We do not recommend nailing these fractures unless other conditions warrant it

METHOD

Length of the Nail.—This is obtained by measuring with a ruler or tape measure the distance from the palpable tip of the medial malleolus to the midportion of the tibial tubercle directly on the good leg in a straight line When the nail is inserted at the level of the midportion of the tibial tubercle the threaded portion will protrude from the cortex and the tip of the nail will be a safe distance from the ankle joint (The nails come with their length stamped on the butt end) In fractures of the midportion of the shaft a shorter nail may be used with safety

Width of the Canal—The narrowest portion of the canal is at the junction of the mid one-third and lower one-third of the shaft. In most cases the 0 37 in (0 93 cm.) diameter nail will suffice however in the very young person a 0.31 in. (0 78 cm) may be needed If in doubt the diameter may be measured by taking a spot x ray film of this region.

Position of the Patient on the Table—The fracture table is used and the patient placed in the usual position with the ankle secured in the foot traction apparatus The thigh is supported by means of a sling under the femur near the knee to an overhead frame If a 2 to 4 in (5 to 10 cm.) stockinette is used for the sling it will act as a good tourniquet when strong traction is applied however if a wider or a padded sling is used it will act as a partial tourniquet and bleeding will be increased The knee rest can be substituted for the sling under the distal part of the femur if so desired The hip is flexed to about 50 degrees and the knee to about 90 degrees

Reduction—Since the tibia is superficial the tibial crest can be palpated throughout its entire length thereby making manual reduction fairly easy Strong traction is applied to distract the fragments in order to facilitate reduction. Rotation is corrected by palpating the crest above and below the fracture site Derotate the crests so that they are in a straight line If the traction is sufficient locking of the fragments can be felt when the displacement is corrected manually after derotation. After reduction the entire circumference of the leg is prepared from the ankle strap to above the knee and draped so that this portion is exposed

Incision—A longitudinal incision is started about one fingerbreadth medial to the mid portion of the tibial tubercle (the upper point used in measuring for the length of the nail) and carried proximally about 1.5 in (3.8 cm) The incision is carried down to the bone in its distal 1 in (2.5 cm.) with the upper

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Lottes J O Blind nailing technique for insertion of the triflange medullar nail: Report of three hundred nailings for fractures of the shaft of the tibia J.A.M.A. 155 1039 1954

0.5 in (1.2 cm.) through skin and subcutaneous tissue only. This is done so as not to enter the knee joint.

Drilling of the Hole.—A 0.37 in. (0.93 cm.) hole is drilled through the cortex at the lower end of the incision just opposite the midportion of the tibial tubercle and near its junction with the shaft of the tibia. If the hole is drilled distal to this level the shaft of the tibia may split during insertion of the nail since the tibia is composed of dense cortical bone in this region. Start the drill at a right angle to the shaft and when the drill bit enters the medullary canal, slowly depress the handle of the drill and aim the tip of the drill at the crest of the tibia at the junction of the mid one-third and lower one-third. Continue to depress the handle of the drill until it actually dents the skin over the knee. Use a flat piece of metal between the drill and the skin to prevent damage to the tissues in this region. While the drill handle is being depressed, use the flat piece of metal against the knee as a fulcrum to bring the tip of the drill forward. This enables the hole to be drilled almost parallel to the long axis of the shaft. It is important to drill the hole in the exact location and direction, otherwise it may be difficult to get the nail started down the canal. If the hole is not drilled as above three things may happen: 1. The nail may cut out through the posterior cortex, thereby making the insertion of the nail extremely difficult. 2. The anterior cortex may split longitudinally below the insertion site, which in itself is not a serious complication. 3. The nail will bend with a posterior bow resulting in a recurvation at the fracture site, which can be corrected at that time or 10 to 14 days later when the cast is changed. A brace type of drill is more suitable than the speed drill.

Insertion of the Nail.—Attach the driver to the nail and insert the tip of the nail in the drill hole with the convex surface of the nail resting on the cortex of the tibia, thereby having the flange on the concave side facing outward. The tip of the anterior flange is aimed at the crest of the tibia at the junction of the mid one-third and lower one-third of the shaft (the same place at which the drill was aimed). The flat piece of metal is again placed between the nail and the skin to prevent damage to the skin during insertion of the nail. Push the nail down the canal until the tip strikes the posterior cortex, then depress the midportion of the nail with the palm of the hand so that the nail is nearly parallel to the long axis of the tibia. At this point the nail should dent the skin over the knee. By this maneuver the tip of the nail is brought forward. With a few sharp hammer blows on the driver the nail will go down the medullar canal and not cut out through the posterior cortex. The nail will continue to dent the skin over the knee and will drive with some resistance. During the entire nailing the penetration of the inserted nail can be checked by using a nail of the same or nearly the same length and laying it on the outside of the tibia. When the inserted nail has reached a point approximately 0.5 in. from the fracture site, reduction and rotation are checked by palpating the crest of the tibia above and below the fracture site. The fracture is held in reduction while an assistant drives the nail a few inches past the fracture site. After the nail has penetrated the canal of the distal fragment a few inches, fixation appears quite stable. If there is excess motion at the fracture site, the nail has not entered the canal of the distal fragment. Partially withdraw the nail and repeat the above process until fixation is stable. If in doubt a roentgenogram in both planes should be taken. The nail is driven down until approximately 1 in. remains protruding at its insertion, then a roentgenogram is taken of the ankle joint in two planes to determine the distance of the tip of the nail from the ankle joint. If sufficient room is present, the nail is driven down until the driver strikes the cortex, thereby leaving the threaded portion of the nail protruding. This will permit extraction of the nail when the fracture is healed. If the nail is too short, especially in fractures of the lower one-third, an extension can be attached to the nail so that it can be driven down to the proper depth. After the nail is driven home the wound is closed in layers and the leg checked for alignment. If either rotation or recurvation is noted, they are corrected by manipulation in place, and a plaster cast is applied from the toes to midthigh. When the nail is being driven down the canal it should advance with each hammer blow. If it does not advance the nail is impinging in the canal and the driving should be stopped. Check the position of the nail in relation to the crest of the tibia. If the flange on the concave side is not in the same plane as the tibial crest the nail should be partially withdrawn and derotated so that the flange is in line with the crest. Then proceed with the insertion. If the flange is in the correct plane and the nail does not advance with each blow, then the nail is too large for the canal and the smaller diameter nail should be used. If in doubt a roentgenogram should be taken in two planes.

Open Fractures of the Tibia

The general principles in the management of open tibial fractures are the same as for other regions (see Chapter 33 on

Treatment of Open Fractures) Prophylac tic pre and postoperative antibiotic ther apy is instituted While the wound is protected with a sterile dressing the foot leg knee and lower thigh are carefully cleansed with soap and water or a deter gent and the skin is painted with an appropriate antiseptic (iodine and alcohol) Sterile drapings are next applied The wound is carefully debrided all foreign bodies are removed and all devitalized tissue excised During the debridement the wound is flushed with moderate quan tities of warm sterile saline solution The fracture is then carefully reduced If the fracture is stable it may require no inter nal fixation but if it is unstable it is im mobilized by appropriate fixation with screws plate and screws Parham bands or an intramedullary nail The type of fixa tion material that is used will depend on the type and location of the fracture and on the personal preference of the surgeon Hemostatis must be complete before the wound is closed In situations where deep hematoma formation is inevitable a rubber tissue drain may be inserted through a stab wound at the dependent portion of the wound (the drain should be removed 24–48 hours later) Attention is then turned toward closing the soft tissue wound without tension If there has been a little or no loss of skin the wound may be sutured in the usual fashion In every case the subcutaneous surface of the tibia must be covered with viable full thick ness skin and subcutaneous tissues When loss of skin and subcutaneous tissue makes direct suture impossible the wound may be closed by means of a local full-thickness skin flap with a broad base this will per mit closure of the soft tissue defect over the tibia without tension The donor site from which the flap has been raised is usually best treated by applying a dry sterile dressing and then 4 or 5 days later covering it with a split-thickness skin graft (see Chapter 35 on Soft Tissue Repairs)

Puncture wounds that are small in size caused by a small sharp bone fragment penetrating the skin from within do not need debridement but may usually be treated by systemic antibiotic therapy local cleansing of the surrounding skin and application of a dry sterile dressing

If there has been extensive skin contu sion and obvious injury to the underlying soft tissues either with or without an open wound the whole leg should be carefully cleansed mechanically prepared antiseptically and covered with sterile sheet wad ding before the application of a plaster casing These areas of devitalized skin should be inspected twice weekly for at least 2 weeks The leg must be kept elevated and completely at rest during this crucial early healing period

The significant incidence of refracture of both the tibia and the fibula following open reduction deserves mention. Refrac ture has occurred following the use of screw fixation as well as with plates In contrast refracture is rarely seen follow ing closed reduction Such refractures usu ally occur from 4 to 7 months after injury and within a few weeks after the plaster has been removed During this critical period the patient should increase his activi ties very slowly and should be guided carefully

Delayed Union and Nonunion of Tibia

The tibia is the most frequent site of nonunion of long bones and the danger of nonunion of fractures of the tibia in adults is ever present particularly in displaced transverse or comminuted fractures In such cases x ray studies should be repeated at intervals and the surgeon should determine as early as possible whether the fracture is (*a*) healing in normal fashion (*b*) healing abnormally slowly (*c*) developing evidence suggesting that nonunion might occur or (*d*) certainly going on to *nonunion*

If the healing process even though de layed is proceeding in normal sequence immobilization should be continued until healing is solid In the 4–6-*month period* of immobilization if there is doubt con

cerning the healing process and if there is a prospect that nonunion may develop an operative procedure designed to improve the local conditions should be considered A simple and usually successful procedure is to expose the fracture line and to pack long shavings of iliac bone subperiosteally around the fracture site (Phemister s method) Following this procedure the leg

the highest percentage of union in established cases of nonunion is onlay bone grafting In some instances pseudarthrosis may be bridged by the bone graft without resection of the fibrous tissue between the bone ends In many cases however it is wise to resect radically the fibrous tissue and the sclerotic bone The medullary canal is drilled to restore its blood supply

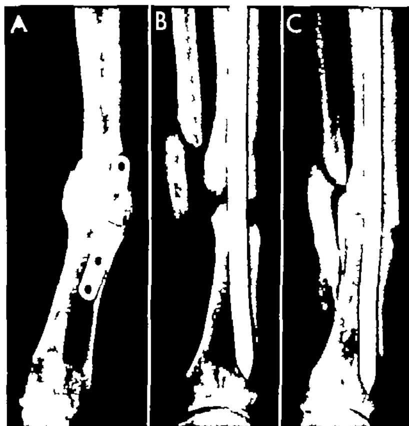


Fig 449 —A, nonunion of tibia and fibula and broken plate B view after plate was removed, fracture ends were freshened Lottes nail was inserted and autogenous iliac bone was placed around the fracture site C 17 months later satisfactory union.

should be reimmobilized in a plaster casing until union is complete

If it is obvious from x ray studies that nonunion is certainly going to occur or if nonunion is already established appropriate surgery should be undertaken As a preliminary to this surgery it may be wise to have a period of 2 or 3 weeks of vigorous exercises to strengthen the quadriceps hamstring and foot musculature and to restore motion to the knee and ankle joints

The surgical procedure that has given

accepting such shortening as is necessary in order to accomplish end to-end apposition of the bone fragments The fracture is then stabilized by means of a full thickness bone graft removed from the proximal fragment or from the opposite tibia the graft being firmly secured to the tibia by 4 screws Additional cancellous bone from the ilium may be packed around the fracture site Postoperatively immobilization is continued until there is definite evidence of union This may require from 4 to 9 months During the early stages of weight

bearing the leg should be carefully protected either with a weight bearing long leg plaster or with a caliper brace

The Lottes or the Küntscher nail has been used as an alternate method of treatment of pseudarthrosis of the tibia in a few cases at the Massachusetts General Hospital Fracture Clinic This method permits early weight bearing while maintaining alignment and permitting impaction The sclerotic bone ends must be drilled to permit insertion of the nail Iliac bone should be placed around the fracture site

For pseudarthrosis of the tibia complicated by osteomyelitis and extensive soft tissue scarring anteriorly a posterolateral approach may be used for surgery (Fig 450) Through this exposure onlay bone grafting or a bypass procedure utilizing the fibula may be done

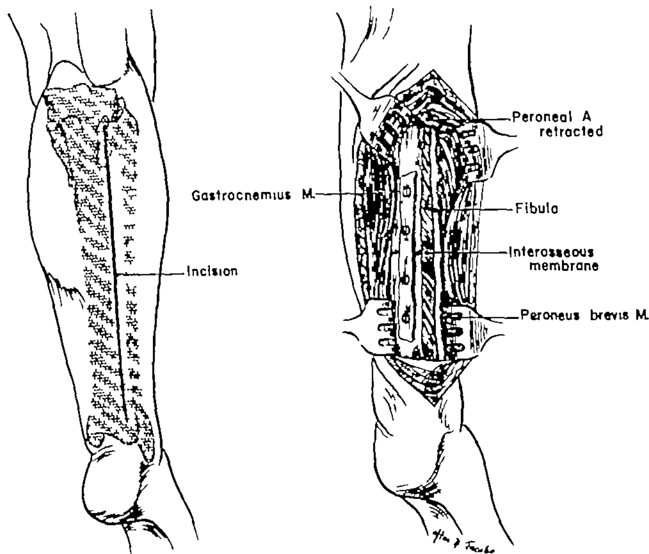


Fig 450 —Posterolateral approach which provides an easy exposure of the posterior aspect of the tibia So often the damaged skin anteriorly precludes safe surgery As shown (right) a tibial onlay graft can be readily applied to the flat lower third posterior tibial surface

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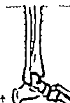
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29 

Ankle Injuries

HISTORICAL

EARLY WRITINGS ON fractures and dislocations of the ankle stressed the seriousness of these injuries The authors reported only a rare cure often permanent disability and not infrequently amputation or death as a consequence Dupuytren (1778–1835) noted that even under favorable conditions fractures of the ankle almost always resulted in deformity and lameness. He reported cures in 202 out of 207 of his own cases with only 2 patients having deformity Five of his patients died We may wonder at his definition of a "cure" but surely we must note his method of splinting (Fig 451)

Credit for development of the modern treatment of ankle fractures and dislocations belongs to Dupuytren Maisonneuve Heister Hönigschmied, Pott Cooper Cotton Ashhurst and Bromer Their works indicate that the proper management of these injuries is based on the mechanism of the injury the pathological anatomy of the bone damage and the effects of muscle pulls In general they stressed the importance of bending the knee and relaxing the gastrocnemius muscle in the manipulation in order to secure easier reduction (Fig 452)

Dupuytren (1816) was the first to record experiments on the mechanism of the production of ankle fractures His theories were accepted until a pupil of his Maisonneuve found an oblique fracture of the fibula in a cadaver Maisonneuve discovered that external rotation was the force that opened the fracture His work on the ankle appeared about 1842. With his clear thinking and logic he presented illustrations of the simplicity of the mechanical forces involved in external rotation violence (Fig. 453)

Hönigschmied (1882) produced mechanically by experimental means almost all the types of fractures of the ankle with the exception of fractures due to compression violence

Ashhurst and Bromer reported an extensive study on the classification and mechanics of fractures of the leg bones involving the ankle (1922) Many others have made *similar detailed analyses* of the mechanics of *these injuries*

All of this material on the mechanics of fractures is interesting and should be reviewed by the student of ankle injuries More recently D Bosworth pointed out the effects of an intact interosseous membrane in preventing the complete reduction of an occasional fracture-dislocation of the ankle The peroneal and posterior tibial tendons have frequently been found

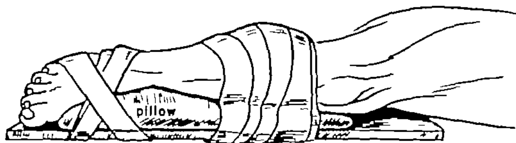


Fig 451 —Dupuytren s splint which incorporates the ideas of inversion and internal rotation of the foot These are the two most important features of reduction in the external rotation injuries

Fig 452.—Manipulation for easy reduction A and B incorrect position—with gastrocnemius muscle taut and knee straight With the leg in this position the muscles are not relaxed and the need for force is obvious C, correct position—all muscles relaxed by bending the knee and putting the foot in equinus

interposed in malleolar fractures So the pathological anatomy of these injuries has broadened to include all tissues in the evaluation of the extent of the trauma

movable rounded and wedge-shaped fulcrum within the tibiofibular mortise produce a great variety of severe ankle fractures and dislocations Running jumping

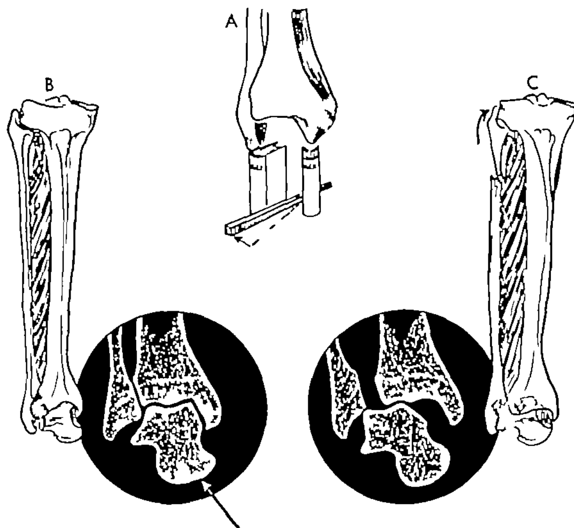


Fig. 453 —Leverage forces in external rotation violence A, illustrating Maisonneuve s simple idea of external rotation violence the malleoli are separated by the force derived from the rotation of the talus B showing direction of fibers of the interosseous membrane (tibiofibular) from tibia to fibula downward The mortise of the tibia and fibula is grooved to fit the contour of the talus. C indicating how an upward force with rotation may produce a high fibular fracture and widen the interosseous membrane and dislocate the talus into a lateral groove

CAUSES AND MECHANISM OF INJURIES

A single misstep on a small pebble or an irregular path or a slippery surface is often all that is necessary to result in a severe ankle injury or fracture-dislocation Falling twisting or turning motions in which the foot becomes a more or less fixed point and the body above becomes the long arm of a lever with the talus as a twisting and sliding motions which are involved in the athletic sports are the common activities having a calculated risk of ankle injury The body in motion above the relatively fixed point of the foot may turn in or out, or fall forward or backward and thus influence the type of fracture-dislocation At the time of injury the type of fracture will vary with the position of the foot i e plantar flexion or dorsiflexion The mechanical features that turn the foot

in or out also increase the variety of fractures Direct trauma, falls from a height, and explosions beneath a standing person —all may produce ankle fractures

A knowledge of the exact mechanism of the injury is useful in reducing the fracture. The use of a reversal of the forces that produced the injury will often result in an easy reduction of the fracture-dislocation and properly applied counterforces will maintain the position of the reduction without strain

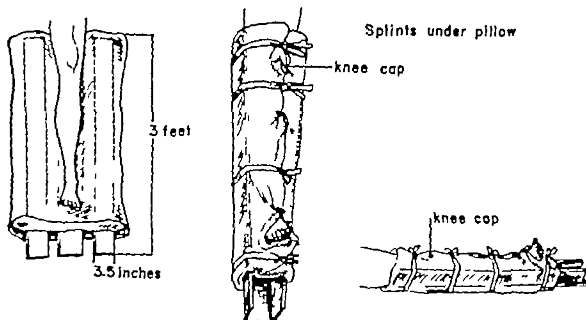


Fig 454 —The pillow-and-sides splint as applied to the ankle One strap extends above the knee and one below the foot.

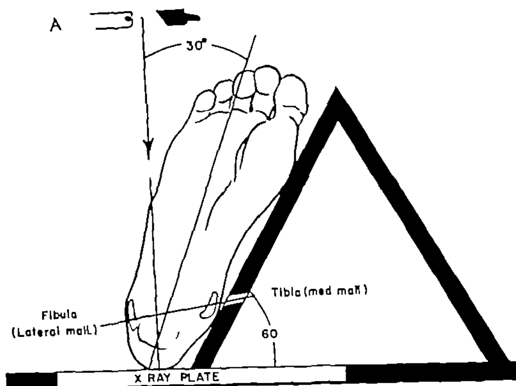
EMERGENCY TREATMENT

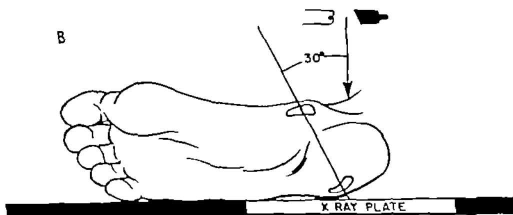
In the first treatment of all injuries the operator should be guided by the principle of early splinting without doing additional harm The best apparatus for emergency treatment of all ankle injuries is the pillow and sides splint (Fig. 454) This splint can be applied by the inexperienced almost as well as by the experienced first aid person In inexperienced hands the rule is to puff the pillow to conform to the deformity and then to apply the side supports and place the third support under the leg and heel Pressure pads are to be avoided over blanched or ischemic skin areas that are "tented" by the deformity In experienced hands it is desirable to apply traction on the foot and ankle in the line of the deformity and then carry the foot around into alignment with the leg before applying the pillow and-sides splint This attempt to straighten the foot and ankle should be done easily to diminish the chance of producing an open fracture or devitalizing the skin over bony prominences The maneuver should not be done in open injuries When there is an open wound a sterile bandage should be applied over the wound and the ankle splinted without reduction of its deformity

The pillow used in the splint should be hollowed lengthwise and the heel should be placed in the hollow just short of the open end of the pillowcase. This allows the end of the pillowcase to extend beyond the side and sole of the foot for support when the sides are folded up This splint is adequate and need not be removed for x ray films. It will be well to study the details of Figure 454

X RAY EXAMINATION

Anteroposterior and lateral views of the foot and ankle are usually sufficient guides for planning the management of the injury The anteroposterior view of the ankle





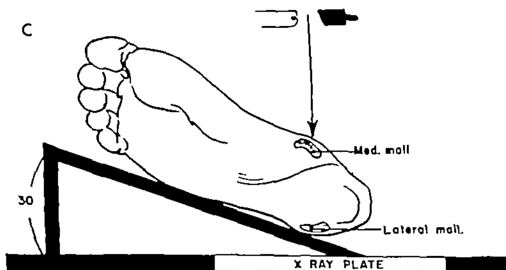


Fig 435 —Positions of foot and ankle for x raying A, foot in internal rotation for true mortise view B lateral side of foot on plate for oblique view with fibula projected behind C toes elevated 30 degrees for a superimposed malleolus view

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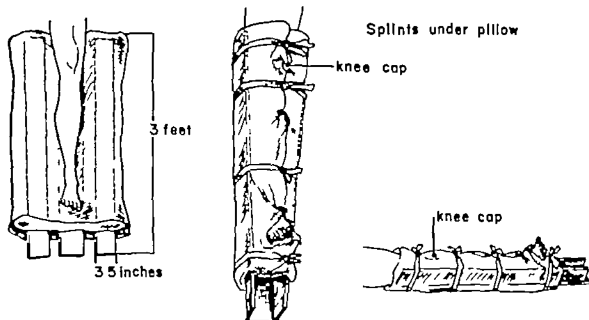


Fig 454 —The pillow and-sides splint as applied to the ankle One strap extends above the knee and one below the foot.

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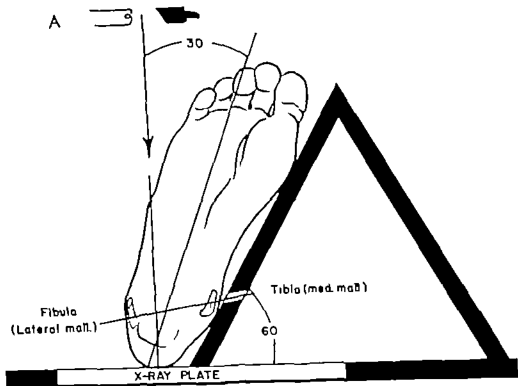
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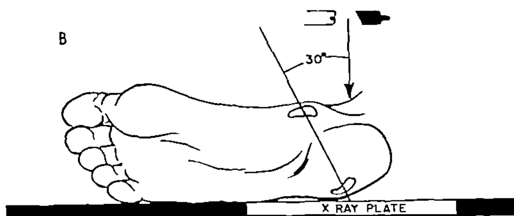
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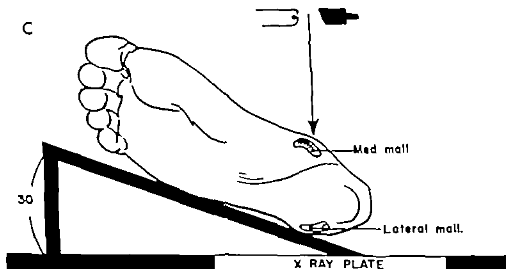


Fig 455 —Positions of foot and ankle for x-raying A foot in internal rotation for true mortise view B lateral side of foot on plate for oblique view with fibula projected behind. C toes elevated 30 degrees for a superimposed malleolus view

will give a clear view of the mortise if the foot is internally rotated about 30 degrees A straight lateral view with the lateral side of the foot on the table will show the profile of the tibia with the fibula slightly behind. With the toes elevated from the table at 30 degrees the malleoli will be super imposed Other angle views should be taken when interpretation of the usual views is difficult (Fig. 455)

X ray films of the fractures and disloca tions are taken at the time of reduction and repeated after the plaster is applied Later the position of the bone fragments should be checked by x ray examination as often as necessary The stability of the reduced fracture and the amount of swelling are leads as to how often such viewing may be indicated A change of plaster may be necessary after swelling has subsided in order to prevent displacement of frag ments In a well molded plaster which has the appearance of a normal foot and ankle a change is seldom necessary

The shaft of the fibula may be broken in ankle injuries Therefore x ray films should include the entire fibular shaft External rotation violence may produce a high helical fracture of the fibula as first pointed out by Maisonneuve X ray films of the other ankle should be taken for com parative studies in unusual injuries and especially in children, in whom growth disturbance may follow epiphysial injuries

ANATOMICAL POINTS OF CLINICAL SIGNIFICANCE

The Talus

The key to the management and under standing of ankle fractures is the talus Because of its wedge shape the talus itself is rarely broken but, mainly because of its wedge shape it breaks the tibia and fibula. And because it is rarely broken, it is the mold for reshaping a badly broken tibia and fibula of the ankle joint (Fig 456)

The ankle articular surface of the talus is convex the anterior margin is wide and the posterior margin about 4–8 mm narrower than the anterior There thus is, mechanically a horizontal wedge with the base forward. The superior surface of the talus is also wider below than above forming another wedge in the vertical plane, with the base below These features constitute structurally a section of a quadrilateral (though not equilateral) pyramid with the top cylindrically rounded and horizontally and transversely grooved from front to back. The groove is roughly in the center 1–2 mm deep and runs from back to front over the entire articular convexity which slopes gently up to the malleolar margins The groove runs parallel with the medial malleolar margin The trochelar surface is thus convex from front to back and concave from side to side The medial margin is longer and lower than the outer one the outer rim is higher and more prominent in front All of the articular edges are rounded The anatomical plan permits the ankle mortise rotatory rock ing and tilting motions comparable to a carpenter s sharp-edged rigid mortise (Fig 456 *A*)

The fibular side or facet of the talus is deeper and more nearly vertical and it faces more posteriorly than the shallow and more oblique medial facet, which faces a few degrees forward and toward the out side Thus these walls are not direct opposites and this accounts for the structural wedges noted above The ankle movements over the talus are not in a direct antero*posterior direction* but along a plane inclined slightly outward This motion is similar to arcs described by two wheels which have slightly different diameters but are fastened to a single axle Such a motion would always be toward the shorter diameter i.e toward the fibula (Fig 456 *B*)

In the anteroposterior x ray view of the talus the shallow groove with slightly elevated and rounded ridges toward each side lies almost in the center of the weight bearing ankle surface

In the lateral x ray view the ankle weight bearing surface is convex above the surface appearing as a part of an arc

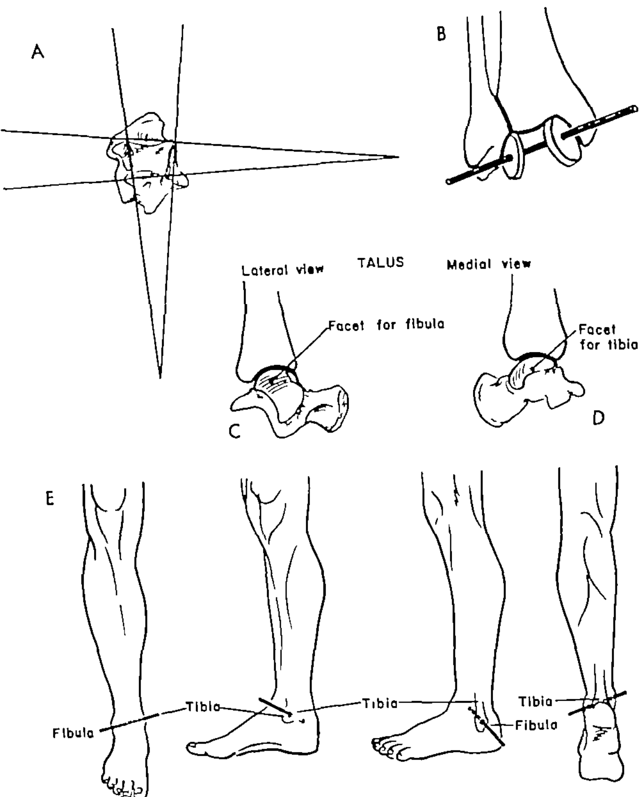


Fig 456 —Important mechanical features of the talus A showing the talus as a part of a wedge with a base in front in the anteroposterior plane and a base medially in the lateral plane Note also that the direction of dislocation and fracture is more often toward the sharp edges of the wedges. B left foot as viewed from behind indicating by the wheel of the fibular facet how functional motions are toward the short arc of motion C facet of the fibula In the vertical plane the facet is elongated and narrow from front to back, allowing a rotation around this arc The foot thus goes into valgus position in plantar flexion D indicating deficiency of tibia in front The base of the talar wedge is forward and prevents anterior dislocation except in unusual violence E, showing relationship of malleoli. These should be restored in reduction

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The ankle articular surface of the talus is convex the anterior margin is wide and the posterior margin about 4–8 mm nar rower than the anterior There thus is, mechanically a horizontal wedge with the base forward The superior surface of the talus is also wider below than above forming another wedge in the vertical plane with the base below These features constitute structurally a section of a quadrilat eral (though not equilateral) pyramid with the top cylindrically rounded and horizontally and transversely grooved from front to back. The groove is roughly in the center 1–2 mm deep and runs from back to front over the entire articular convexity which slopes gently up to the malleolar margins. The groove runs parallel with the medial malleolar margin The trochelar surface is thus convex from front to back and concave from side to side The medial margin is longer and lower than the outer one the outer rim is higher and more prominent in front All of the articular edges are rounded The anatomical plan permits the ankle mortise rotatory rock ing and tilting motions comparable to a carpenter s sharp-edged rigid mortise (Fig. 456 *A*)

The fibular side or facet of the talus is deeper and more nearly vertical and it faces more posteriorly than the shallow and more oblique medial facet which faces a few degrees forward and toward the out side Thus these walls are not direct opposites and this accounts for the structural wedges noted above The ankle movements over the talus are not in a direct antero-posterior direction but along a plane inclined slightly outward This motion is similar to arcs described by two wheels which have slightly different diameters but are fastened to a single axle Such a motion would always be toward the shorter diameter i e toward the fibula (Fig 456 *B*)

In the anteroposterior x ray view of the talus the shallow groove with slightly elevated and rounded ridges toward each side lies almost in the center of the weight bearing ankle surface

In the lateral x ray view the ankle weight bearing surface is convex above the surface appearing as a part of an arc

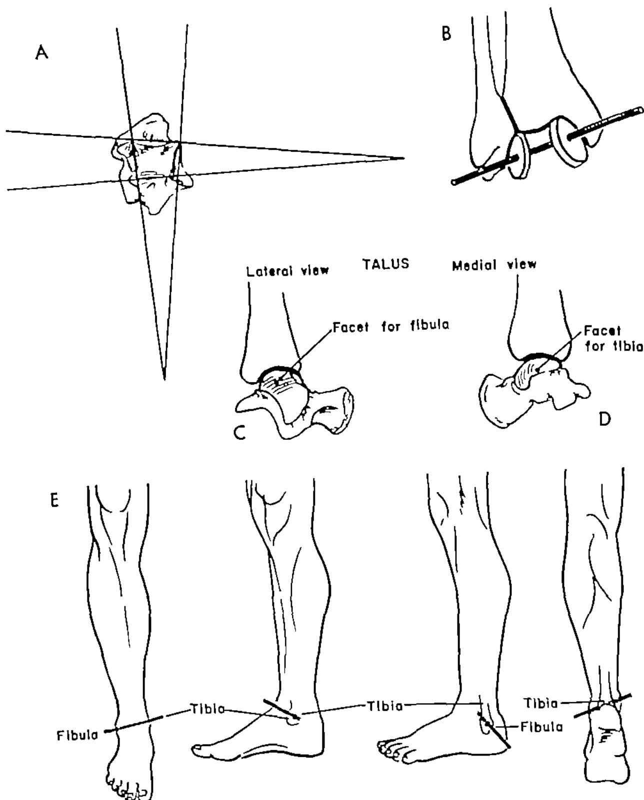


Fig. 456 —Important mechanical features of the talus A, showing the talus as a part of a wedge with a base in front in the anteroposterior plane and a base medially in the lateral plane Note also that the direction of dislocation and fracture is more often toward the sharp edges of the wedges B left foot as viewed from behind indicating by the wheel of the fibular facet how functional motions are toward the short arc of motion C facet of the fibula In the vertical plane the facet is elongated and narrow from front to back, allowing a rotation around this arc The foot thus goes into valgus position in plantar flexion D indicating deficiency of tibia in front The base of the talar wedge is forward and prevents anterior dislocation except in unusual violence E, showing relationship of malleoli. These should be restored in reduction

of a circle Flexion and extension motions of the ankle joint thus have an axis of movement transversely through the body of the talus at about the level of the tip of the fibular malleolus The projection of a radius from this arc will present an axis for motion approximately as described above This points to the location of a joint in an ankle brace with the center of motion at the tip of the fibular malleolus The radius of the medial arc falls slightly below this because of its slightly flatter surface (Fig. 456 C and D)

The Distal End of the Tibia (Ankle Articulation)

At its distal end the tibia enlarges from roughly a midshaft triangular shape to form to a quadrilateral shape at its base This enlarged structure fits over and above the body of the talus with a weakness on the lateral side The lower end of the fibula fits in a shallow concavity on the lateral side of the tibia and projects distally as the lateral malleolus The articular flare of the tibia is wider in front and a few millimeters higher and shallower than the narrower posterior lip

The inferior articular surface of the tibia is concave from front to back and roughly quadrilateral broader in front than behind and has a slightly elevated ridge running from front to back parallel with the medial malleolar concavity During movement this ridge seats itself on the groove of the trochlear of the talus This whole surface covers about two thirds of the talar ankle articulation Medially the internal malleolus projects downward and has a shallow articulation with the talus which slants away from the body at an obtuse angle The entire tibial ankle surface is within the margins of the enlarged distal end which has its greatest diameter about 1 cm above the articular surface From this enlarged area the tibia is rounded on all sides to meet the smaller area of articular surfaces This rounded area serves as the attachment of ligaments and capsule

The Distal End of the Fibula

The lower end of the fibula is the external malleolus which is about twice as lon as and projects down beyond the tip o the medial malleolus The center of th fibular malleolus is slightly behind th transverse axis of motion. The bimalleol axis and the axis of movement meet at a angle of about 30 degrees The articul face of the fibular malleolus is conve from above downward toward its talar ar ticulation but in horizontal cross-section it is slightly concave This structural fea ture adds to the strength and stability of the fibula in rotatory motions.

IMPORTANT LIGAMENTS OF THE ANKLE

The ankle joint is enclosed by an articular capsule This capsule is thin and weak anteriorly and posteriorly Laterally it is strengthened by the anterior and posterior talofibular ligaments to form the fibular collateral ligament Medially it is very strong and forms the deltoid ligament The fibula is attached to the tibia by strong anterior and posterior tibiofibular ligaments. The fibers in general run from the tibia above outward and downward to the fibular malleolus below The interosseous membrane of the tibia and fibula has fibers running in the same direction This arrangement allows the fibula to move out and slide upward a slight amount on weight bearing and especially during dorsiflexion of the ankle (Fig 453)

The ligaments which should be considered in the functioning of the ankle are:

1 Mortise ligaments
   a) Anterior and posterior tibiofibular
   b) Interosseous membrane tibiofibular
2. Medial ligament (deltoid)—tibial collateral
   a) Anterior talotibial
   b) Posterior talotibial
   c) Calcaneotibial
3 Lateral ligament—fibular collateral
   a) Anterior talofibular
   b) Posterior talofibular
   c) Calcaneofibular

A superficial ligament which encircles

the ankle and holds the tendons in their sheaths is known as the cruciate crural band

MUSCULAR AND TENDON ANATOMY

The surgically important anatomical features of the ankle are shown in Figure 457

Plantar flexion through the Achilles ten don is carried out by the gastrocnemius-soleus muscles The gastrocnemius muscle arises from above the knee and the knee must be bent and the foot kept in plantar flexion to obtain relaxation of these mus cles. The soleus the peroneals and the posterior tibial muscles and all the long toe flexors are also plantar flexors of the foot and ankle but only the equinus posi tion of the foot is needed to relax them Tension on one muscle group and relaxa tion of the opposing one is often essential in maintaining the reduction of fractures and less or more tension may be necessary to prevent the development of a deformity during healing

The tendons that are most important in controlling the fracture fragments about the ankle are (1) the Achilles tendon (2) the peroneal tendons (3) the poste rior tibial tendon, and (4) the flexor hallu cis longus tendon.

The heel cord (*Achilles tendon*) is taut when the knee is straight and the foot is at a right angle A redislocation posteriorly may occur even in plaster unless the force through the heel cord is relaxed by bend ing the knee and letting the foot drop into equinus

The *peroneal tendons* pass behind the fibular malleolus under its tip and then forward the fibula is a grooved pulley around which these tendons slide in func tion In passive plantar flexion of the ankle the tendons are relaxed. In dorsiflexion they are also taut and with a broken fib-ula, the pressure exerted on the tip of the fibula will be forward and will displace or tilt the distal fragments backward at the fracture site A slight equinus and varus position lessens this tension and diminishes the chance of redisplacement of the fragment

The *posterior tibial tendon* passes be hind and in a groove of the medial mal leolus In a fracture of the medial malleolus this tendon when taut will push forward on the fracture causing separa tion of the fracture anteriorly because the intact deltoid ligament holds the distal fragment down A slight equinus position will relax the tension on the posterior tibial tendon and rock the narrower and shal lower portion of the talus into the tibial mortise which also relaxes the ligamen tous tension Direct molding of the malleolus into alignment is thus often possible in slight equinus and varus position. Inter position of periosteum or other soft parts often occurs in this fracture

The *flexor hallucis longus tendon* passes directly behind the tibia in a groove at the ankle and obliquely from the lateral to the medial side (Fig 457 *B*) In the passive equinus position the tendon is relaxed but dorsiflexion of the great toe as the ankle is brought into dorsiflexion will put tension downward and forward on the posterior margin of the tibia The lip fragment will then stay in position even with the foot and ankle in slight equinus provided that the retaining forces are forward toward the remaining sound articular surface of the tibia. The proper use of forces through this tendon will help to reduce the posterior tibial lip fragment and maintain its posi tion

MOTIONS OF THE ANKLE

In walking as the foot hits the ground it becomes a fulcrum and the ankle joint acts as a hinge The body above the ankle has a tendency to continue forward because of its momentum The weight of the body placed on the ankle would thus be transferred forward onto the dorsum of the foot were it not for the wedge shaped talus with its base in front As the force slides forward on the talus the malleoli are pressed tightly against the sides of the talus with increasing force This force is present because of the following anatomi

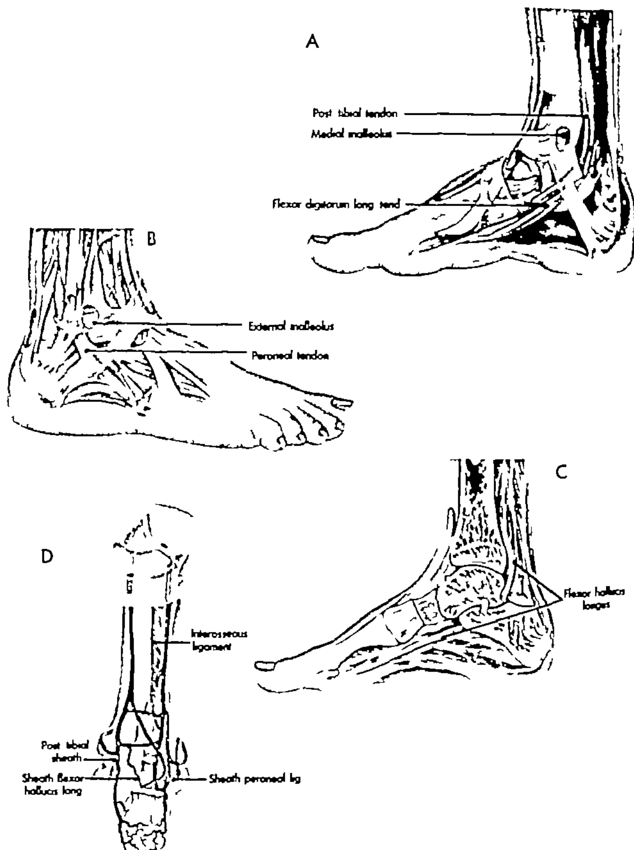


Fig 457 —Surgically important anatomical features of the ankle A and B arrangement of tendons which produces pulley forces on the malleoli. C and D position of the flexor hallucis longus tendon in cross-section and (below) its groove from behind The strength and weakness of the ligaments and the abundance of the blood supply and anastomoses around the ankle should be understood by the surgeon

cal factors As the tibiofibular mortise slides over the talus from its narrow to its wide surface in front the fibula is made to move out and up to adjust to the wedge shaped talus thus keeping articular surfaces apposed during flexion and extension It is easy to demonstrate that the as the foot goes into plantar flexion bringing the posterior margin of its talar facet against the narrower margin of the talus *This external rotation and downward motion* is aided by the tension on the flexor muscles attached to the posterior margin of the fibula high on its shaft The action

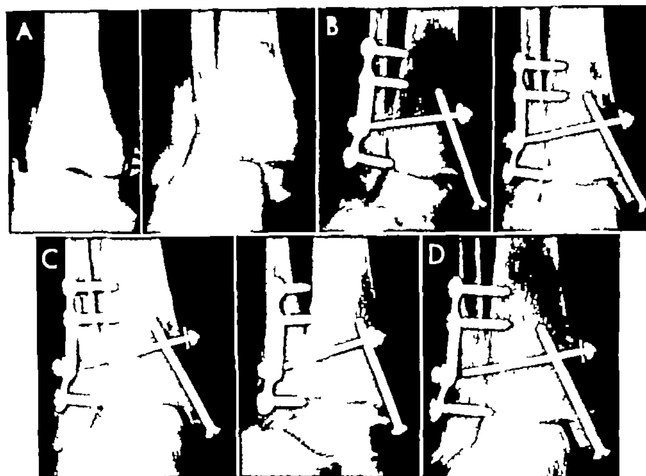


Fig 458 —The fallacy of rigid fixation of the lower end of the tibia to the lower end of the fibula A, lateral and anteroposterior views of ankle showing injury with displacement. The films do not indicate a need for excessive internal fixation material. B oblique and anteroposterior views reveal "rigid fixation" of the tibia to the fibula C anteroposterior view showing bolt which broke with weight bearing function The surgeon should plan to remove all transfixation bolts that hold a ruptured tibiofibular ligament D anteroposterior view showing atrophy of bone around the broken bolt, attesting to the validity of not making the tibiofibular ligament solid

fibula glides up and down and slightly in and out by placing the thumb on the head of the fibula while touching the tibia and *then actively moving the ankle through a* full range of motion The head of the fibula will rise and become prominent with the foot in dorsiflexion and descend and be less prominent in plantar flexion There is also a slight rotation of the fibular shaft of the peroneal tendons on the posterior margin and tip of the fibula also aid in this narrowing of the mortise The direction of the fibers of both the tibiofibular ligament and the interosseous membrane (from tibia obliquely down to fibula) allows widening of the mortise and interosseous space on the ascent of the fibula. These spaces could only become narrower

if interosseous fibers had a reverse direction.

Since ligaments are not elastic the resilience of the ankle must be accounted for in the muscles themselves The major portion of the soleus and posterior tibial muscles and all of the flexor hallucis longus muscle arise from the shaft of the fibula Muscle tension on this group as in plantar flexion would push the fibula lower and against the sides of the talus at its narrow margin It is obvious that a rigid fixation of the tibia to fibula is not intended and should not be attempted The bolts wires and screws that have broken after attempts at tibiofibular rigid fixation attest nature s resistance to this treatment These agents may be used for temporary internal fixation during the healing time of ligaments and then should be removed If not removed they will break or loosen as function of the ankle is restored (Fig 458)

In any one position the tibia covers only about 50–60 degrees of the available 90–100-degree arc of the articular surface of the talus. The difference equals the true ankle motion of about 40–50 degrees Since the amount of joint motion varies with body types so also does the amount of available joint motion vary in the ankle

LIGAMENTOUS INJURIES

Of all the ligamentous injuries of the body those of the ankle are most common and least understood Also they are often poorly managed The reason for this is clear from our knowledge of the anatomy and normal function of the ankle Any impairment of the function or distortion of the anatomy can be determined by a careful examination A systematic palpation of the joint will usually reveal the extent of injury X ray studies are only a part of a complete examination they should be ordered only on the basis of their indications not routinely

The diagnosis of a sprain is made by the history of the injury and by the fairly rapid swelling and stiffness of the joint which followed the injury plus the increased pain on walking. A local examination will reveal the point of maximum tenderness and swelling with aggravation of pain at this point when the ligament is stretched or placed under strain. A combination of ligaments may be injured Active and passive motions should be carried out with gentle attempts at strain positions of inversion, eversion, and rotation. Forward and backward pressures on the foot through the ankle will reveal any instability in these directions

For management purposes ligamentous injuries may be divided into (1) sprains with tears of a few fibers but without instability (2) ligamentous tears with demonstrable relaxation of the involved ligament, and (3) complete ruptures

The treatment of a sprain may be completely symptomatic and directed toward a reduction of the swelling by the use of elevation and gentle compression with or without local applications of ice Because early return of function is desirable some physicians advocate the use of local Novocain® infiltration or ethyl chloride spray These agents should be used only in rare and unusual cases The return of ankle function can be accomplished by supported weight bearing with adhesive strapping (Fig 459) and crutches active exercises, and mild compression for the reduction of swelling Ten days to 2 weeks time is usually sufficient for recovery from these partial tears—recovery without instability of the ankle joint (Fig 460)

Partial tears and completely ruptured ligaments need individualized treatment. A complete tear of either collateral ligament may need surgical repair Snug supportive plaster treatment for from 5 to 8 weeks is necessary for ligamentous healing Experimental studies on healing show firm union of ligaments in 4 or 5 weeks but a persistence of cellular infiltration for 2–3 weeks more Support by strapping should be continued throughout this period

Restoration of function includes the re-

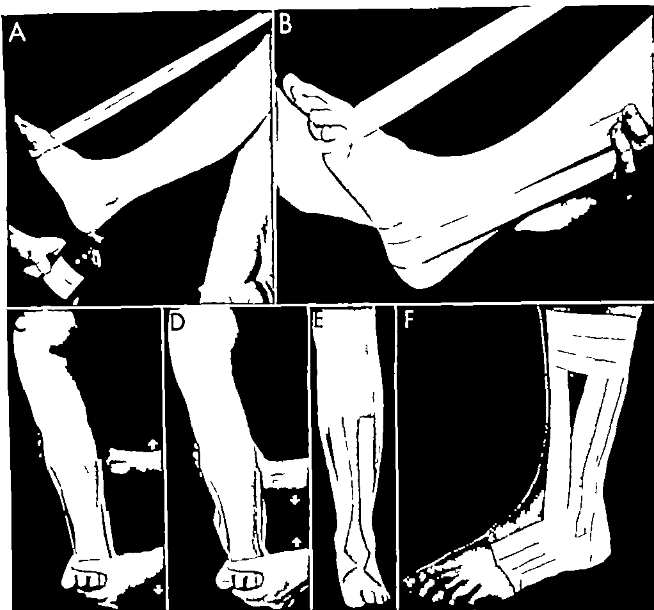


Fig 459 —Technique of ankle strapping The carefully shaved and cleansed skin should be protected (A) under the strapping with a suitable material like tincture of benzoin Inelastic lateral supports (B) put on without tension should be used to bridge the gap around the malleoli. With the skin under normal tension the lateral straps are taut as in C. With the skin of the calf pulled toward the heel as in D the straps of adhesive become relaxed Lateral pressure over these straps will thus mold easily over the malleoli. Extra lateral straps of adhesive (E and F) are added with as few wrinkles as possible and the heel and sole are completely boxed in (continued)

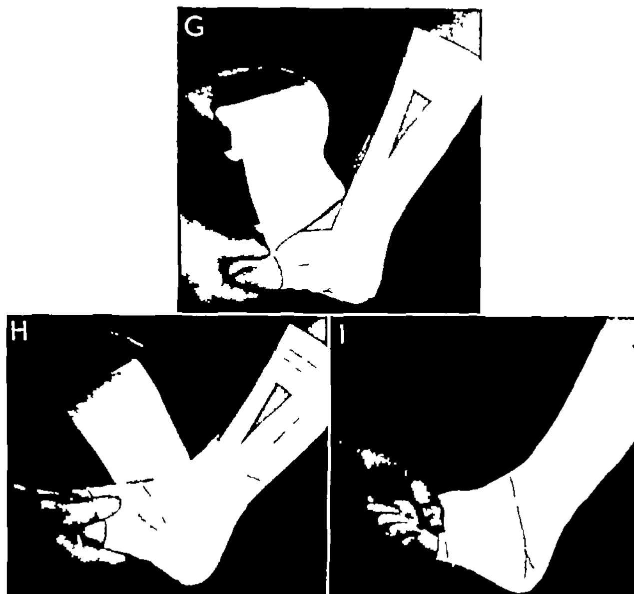


Fig 459 (cont) —An elastic adhesive is added around the foot and ankle (G); it is brought across the front of the foot without tension The final supportive turn around the ankle (H) crosses the point of the heel so that the heel is completely covered. Care is taken not to pull the bandage tightly across the front of the foot and ankle and not to pull it tightly across the Achilles tendon It should be snug under the malleoli and sole of the foot The final turns of the bandage (I) should be smoothly and loosely applied

gaining of muscle strength and the return of joint motion Special emphasis must be placed on the prevention of contracture of calf muscles and pronation of the foot by the use of adequate strength building and muscle-building exercises Anterior tibial *pull toe pressing and heel cord stretching* exercises are the exercises of choice These can be done by having the patient rock forward on his toes and back on his heel while carrying the weight toward the outer side of the foot through the entire motion (Fig 461) Balancing and the use of progressive resistance exercises may be added as necessary No program of treatment of ankle injuries is complete without the use *of active exercises and neither* treatment nor supervision is over until strength has been regained and until joint function has been restored.

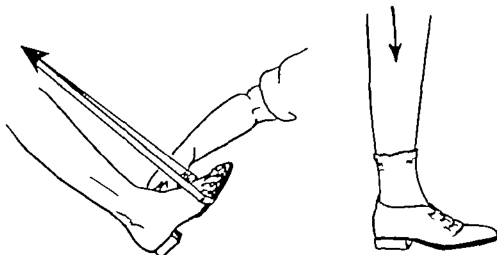


Fig 460 —Ankle strapping in a functional position In strapping an ankle for support after a strain or on removal from plaster the patient should hold the ankle in the proper position—that is in equinus (left) which should be estimated to be the relaxed position of the foot within a shoe allowing for the usual shoe heel (right)



Fig 461 —Exercises for the foot and ankle using a homemade rocker The patient should support himself by means of a table chair back or crutches The limbering up of the subtalar joint and the strengthening of the tibials and peroneals can be markedly aided by side rocking (A) Stretching the calf muscles and heel cords and exercises in balance are also easily carried out on such a rocker (B) By thus actively exercising both feet, the normal foot guides the injured one

BONE INJURIES

Types of Bone Injuries

The diagnosis of bone injuries of the ankle is made by the history and physical examination X ray studies should be used for confirmation of the physical findings and for guidance in the management of the entire injury A simple classification of the types of bone injuries is useful in studying in planning the management of and in estimating the prognosis of individual cases The following outline fills these requirements

- I. *Malleolar fractures*
  - A Isolated
    - 1 Fibula
      - a) Malleolus alone
      - b) With tibial collateral ligament injury
      - c) With tibiofibular ligament injury
      - d) With high shaft fracture
    - 2. Tibia
      - a) Malleolus alone
      - b) With fibular collateral ligament injury
      - c) With tibiofibular ligament injury
  - B Combined
    - 1 Bimalleolar with dislocation
    - 2 Bimalleolar without dislocation
- II. *Tibial weight-bearing surface fractures*
  - A Isolated
    - 1 Anterior marginal
    - 2. Posterior marginal
  - B Combined marginal fractures with malleolus fractures
    - 1 Anterior
    - 2. Posterior (trimalleolar fracture)
    - 3 Lateral margin
- III *Avulsion fractures*
  - A Tips of malleoli
  - B Tibiofibular ligament avulsion

Open Wounds with Fractures

The injuries listed above may of course be complicated by open wounds and will then require the special care that is required of all open injuries with bone involvement The surgical aim is to close viable skin over bone without devitalizing tensions or improperly applied compression dressings

The poverty of skin and soft tissue around an ankle compared with the amount of enclosed bone is most apparent in a study of a cross-section through the malleoli (see Fig 457) A small amount of swelling puts a relatively great stretch on the skin of the ankle at an area where the skin circumference is minimal. Owing to this anatomical feature the skin should be preserved at the expense of other tissues particularly bone and even at the sacrifice of fracture position. A good reduction may be lost and joint function put in jeopardy by the loss of skin or by leaving open wounds around a joint. Secondary operations to correct fracture positions and restore joint function are more successful through healed skin Therefore accurate *reduction of the fracture may assume* a secondary role in open fractures.

Closed Manipulations

All ankle fracture-dislocations deserve well thought-out tries at closed reduction. It is helpful although not always possible to reconstruct the mechanism of injury and apply a reversal of forces in the reduction manipulation If the type and extent of the injury is understood by an examination of the ankle and an evaluation of the x ray films it is often possible to manipulate *loose fragments of* bone out of the joint and away from important weight bearing areas or supporting surfaces without resorting to surgery

When to Reduce a Fracture

The best time to reduce any fracture is immediately after it occurs If a severe fracture-dislocation of the ankle is seen within a few minutes after the injury it is possible to reduce and maintain reduction very easily even without the use of anesthesia No ankle fracture is too swollen to be reduced It is not correct to wait until the swelling goes down before reducing a fracture Swelling will go down after the fracture is reduced and usually not very rapidly before If there is extensive swelling—even with fracture blisters—before there is opportunity to treat the fracture

it is possible to use a compression dressing to help reduce the swelling while the pa tient is being anesthetized In a very mark edly swollen ankle the use of an Esmarch bandage for 10–15 minutes after the re duction has been obtained diminishes the swelling so that the malleoli can be felt easily and molded with the plaster to pre vent the cast from becoming too loose too rapidly after reduction. This procedure has been used even in the presence of fracture blisters

General Principles of Manipulation

The general principles of manipulation are shown in Figure 462

Traction in the Line of Deformity —In addition to reducing swelling it is also necessary to relax the muscles producing the deformity or resisting its cor rection. In the ankle these muscles are the plantar flexors Therefore the knee must be flexed to relax the gastrocnemius muscle and the foot must be put into equinus to relax the plantar flexors

The knee should be bent at a right angle and the foot held in equinus during trac tion While the traction is maintained a slight increase in the deformity should be made before the distal fragments are brought around to meet the proximal frac ture surface This maneuver prevents breaking off the fracture spicules which will help to maintain reduction and aid in bone union

Correction of the Deformity —After restoration of length by traction correc tion of the deformity is easily accom plished Leverage forces against intact bone pulley forces through tendons and traction forces through intact ligaments should be utilized to correct the deformity and to maintain the reduction The lever age forces are to be applied as indicated in individual cases The pulley forces through the peroneal and posterior tibial tendons can be used to bring the malleoli forward It must be remembered however that too much force through these tendons by right angle dorsiflexion of the foot will tilt a fibular fragment backward at the frac ture site and a medial malleolar fragment down and forward (Fig 463) After reduction these forces should be released sufficiently to maintain position. Because of its posterior anatomical position in crossing the distal tibia at the ankle joint, the tendon of the flexor hallucis longus can be put under tension so that it will push forward on the posterior marginal fracture and hold it in place For molding of fragments direct pressure over bony prominences may be used during the ma nipulation

Maintenance of Position of Fragments —While the position of the frag ments is being maintained the foot should be held (as nearly as possible) in an angle of proper function Only minimal strain forces are needed to maintain reduction in a light, thinly padded and well-molded plaster casing The plaster should have the shape of the foot and ankle and should be smoothly molded around the Achilles ten don and heel, the malleoli and the sole of the foot. As the plaster sets slight pressure should be put uniformly on the sole of the foot toward the intact articular surfaces and ligaments

Immobilization of the Fractured Ankle

One of the chief problems in the management of ankle fractures is the maintenance of reduction The skillful application of a well molded plaster is as important as the proper reduction. To con trol the extremity after reduction and to apply a plaster casing the surgeon needs two assistants—one to hold the knee and the other to apply the plaster bandages The surgeon should maintain the reduc tion of the fracture (Fig 464) until the plaster has been rolled above the ankle he should then mold the plaster around the malleoli so that the outline of the Achilles tendon and the two malleoli are clearly visible in the plaster casing. Only enough padding should be used to protect the bony

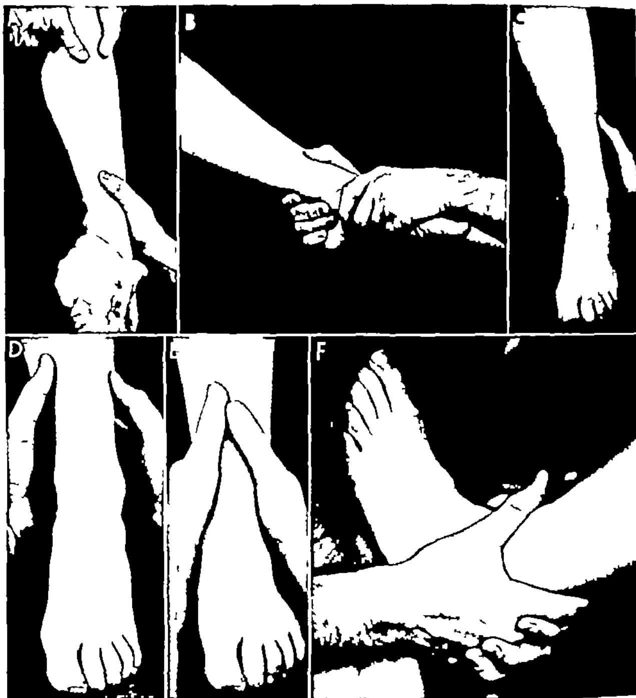


Fig 462.—Principles of reducing ankle fractures A the first position, as viewed from above. The knee is supported in flexion for countertraction either by an assistant or by flexion of the knee over a knee sling or support The surgeon s hands are applied to the foot and ankle The hand on the outer side of the foot grasps the foot and ankle over the fibula, the fingers hooking behind the heel and extending around to the medial malleolus The hand on the inner side of the foot grasps the foot palm of hand on dorsum of foot (This traction position of the hands places the left hand on the top of the left foot) In a more medial view (B) the fingers of the hand on the outer side hook behind the heel and end below the medial malleolus. The index finger remains behind the malleolus C showing the ease with which the relative positions of the malleoli can be outlined and how naturally the contour of the palm of the hand can be adapted for molding the malleolus D position of hands for molding the malleoli. The concavity of each palm fits over each malleolus and so a wide distribution of pressure can be placed evenly over these bony prominences (This same positioning of the hands is used in molding the plaster casing) E closing the palms over the malleoli the palm on the medial side

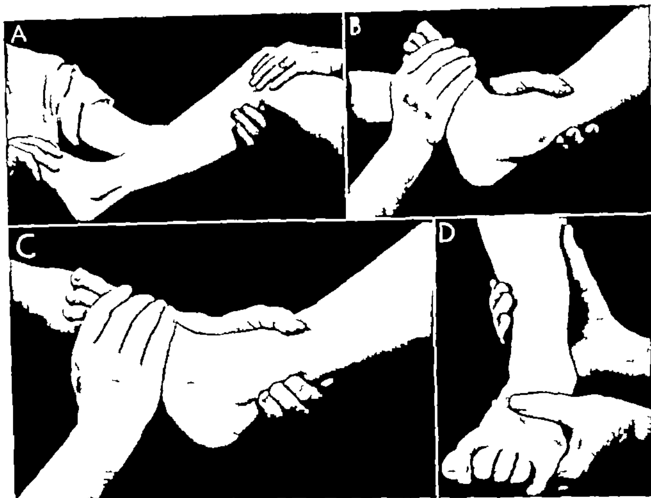


Fig 463 —Tendon pulley forces on malleoli A reduced fracture is most easily held by pressure toward the opposing ankle surfaces A, the taut peroneal tendon with the foot at a right angle A slight equinus position relieves this tension The tendon pulley force of the peroneals can be seen when the foot is forced into dorsiflexion (B) this force will tilt a fibular fracture posteriorly By lowering the foot into a few degrees of equinus and using pressure posteriorly over the fibula (C) a posterior angulation can be reduced Rotatory positions can be easily controlled with the hands in this position The most important position to obtain in fibulomalleolar fractures is a restoration of length and then a correction of the external rotation These features can be controlled (D) by pulling on the tibia with the right hand and pushing with the left and by pushing the calcaneus into varus position internally rotating the foot, and depressing the first metatarsal.

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of the foot is higher and more anterior than the one on the lateral side The difference in height of the malleoli is approximately the length of a thumbnail as shown in the illustration F the final positioning of the reduction—the fingers locked above the heel and behind the Achilles tendon The sole of the foot is supported on the surgeon s sternum. In this position the ankle can be gently rocked in dorsal and plantar flexion while lateral pressure is maintained over the malleoli Rotatory positions will normally be assumed by the seating of the talus into its normal grooves with the lower articular end of the tibia An understanding of good x ray films will help guide the surgeon during the application of gentle pressure toward the more intact articular surface

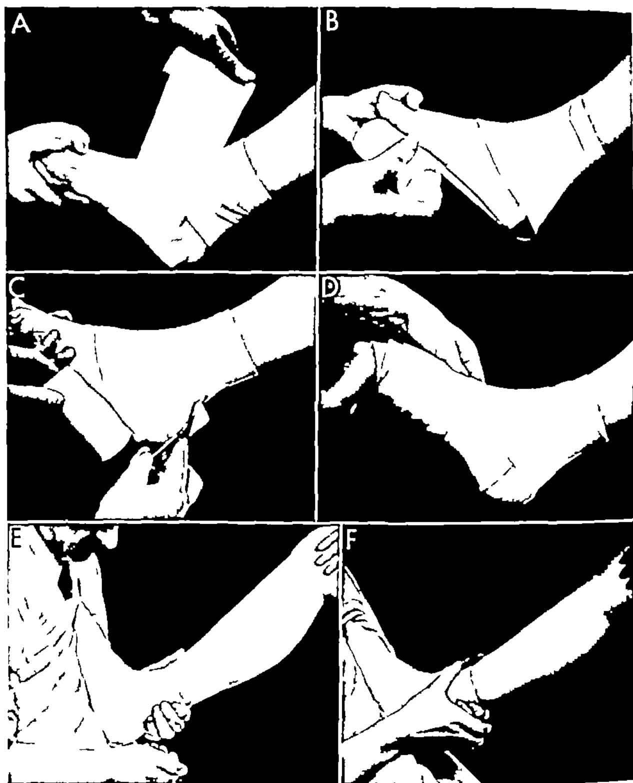


Fig 464 —Technique of padding preliminary to plaster application The first turns of padding (A) as well as the first turns of plaster bandage should start at the point of smallest diameter which is above the malleoli The padding of sheet cotton should be as free from wrinkles as possible Further turns of padding and plaster bandage above the ankle (B) should be made snug (not tight) under the malleoli. Additional turns should reverse around the heel and then cross the point of the heel without tension The darts should be cut off (C) to keep wrinkles at a minimum. The final turns of padding and plaster bandage should cover the fingers of the assistant who is holding the toes (D) This extra room allows loose molding of the cast after the plaster bandages are fully applied and prevents tightness around the toes. The posi-

prominences The plaster should not be so thick that the underlying parts cannot be readily palpated in molding the cast At all times the entire extremity should be under the control of the surgeon If the lateral malleolus is fractured there should be gentle pressure through the plaster on the lateral side of the malleolus and the foot should be in slight varus position to maintain the length of the fibula If the medial malleolus is fractured then the medial surface of the medial malleolus should have gentle pressure exerted on it through the plaster Reduction of a fracture of the anterior or posterior lips of the tibia can likewise be maintained through gentle pressure exerted by the casing—pressure which was produced as the casing was molded over the fracture line Before the application of the plaster-of paris bandage the surgeon should have studied the x ray films well to determine what forces should be applied through the casing to maintain reduction

Postreduction and Postoperative Care of Fractures of the Ankle

Following manipulation or open reduction, the extremity should be protected from dependency for several days to prevent extra swelling within the plaster casing. It is advisable to keep the leg elevated above the level of the heart until some wrinkling of the skin on the leg is apparent Increasing dependency is then allowed according to the amount of swelling of the toes occurring on dependency The patient should be warned of the danger signs of vascular obstruction and taught how to protect against it. Those attending the patient postoperatively should be instructed to check the color sensation and function of the toes frequently during the first 24 hours After reduction and immobilization the extremity should not be very painful If there is persistence of pain blanching cyanosis or loss of sensation in the toes the causes of these disturbances should be investigated without delay The common causes of these disturbances are improper elevation too tight a plaster inadequate reduction and pressure spots from a poorly fitting plaster

If the symptoms are not relieved by properly positioning the leg in bed then a thorough re-evaluation is indicated The symptoms should not be treated with medication for pain Swelling within the cast is not uncommon and the surgeon should not hesitate to split and spread the plaster and the underlying padding to relieve constriction With persistence of symptoms and signs after these things have been done x ray films should be taken to determine whether reduction has been maintained It is not uncommon for ankle fractures to require a second manipulation and nothing is to be gained by delay As in all other phases of the management of fractures the attention to details is of the utmost importance

Medial Malleolus Fractures

In the case of an isolated medial malleolus fracture simple manipulation is often successful. The foot is brought into slight equinus and the heel held in varus position with pressure toward the fibula The palm of the right hand (for a right ankle) is used to mold the malleolus toward its fractured end A final position of slight equinus will prevent the posterior tibial tendon from pushing the medial malleolus forward If it is not possible to hold the

tion of the ankle is now maintained by the surgeon (E) with pressure through the sole of the foot toward counterpressure through the knee The surgeon's fingers behind the fibula exert pressure forward to prevent posterior angulation. With both of his hands locked behind the heel (F) the surgeon can accurately control the equinus position by lifting the heel forward on the hands and leaning backward. The reverse will diminish the equinus. The ankle can thus be rocked through its functional motion to its most stable position Notice that the hand over the medial malleolus is placed higher on the leg.

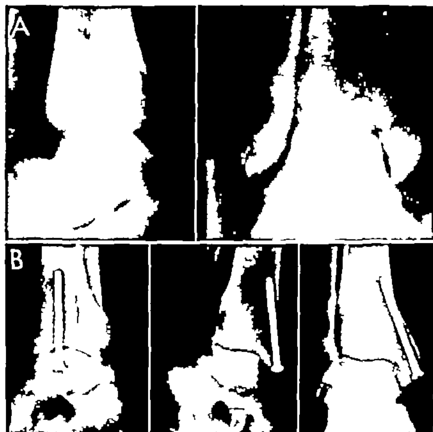


Fig 465 —An elective open reduction. Although there was some question as to the advisability of carrying out an open reduction on this fractured ankle (A lateral and anteroposterior views) the medial malleolus was stabilized (B lateral, oblique and anteroposterior views) This provided a firm side to the ankle mortise The fibular length was thus restored and maintained without fear of displacement of the talus medially While excellent function may have been obtained without medial malleolar fixation function was assured by the fixation

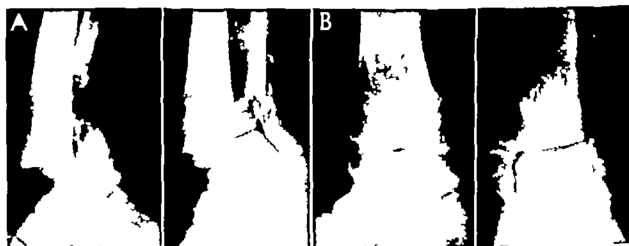


Fig 466 —Management of a severe injury by closed reduction A lateral and anteroposterior views of severe bimalleolar fracture with dislocation There is a good intact articular surface on the tibia In such fractures the collateral ligaments are intact and the talus will seat normally in the tibial concavity B 1½ years after fracture dislocation an asymptomatic nonunion of the medial malleolus. The ankle is stable and has a normal range of motion The medial malleolar fracture was below the ledge of articulation and so there is stability in weight bearing. At the time of injury the periosteum was probably pulled across the proximal fractured end of the medial malleolus where it remained, interposed as a fibrous tissue



Fig 467 —Management of bimalleolar fractures with wire sutures and one screw A mini mum of internal fixation material should be used to hold reduction. At times wire sutures will hold an oblique fibula with excellent results. No one method should be used. The fractures should be managed according to some basic principles and individualized

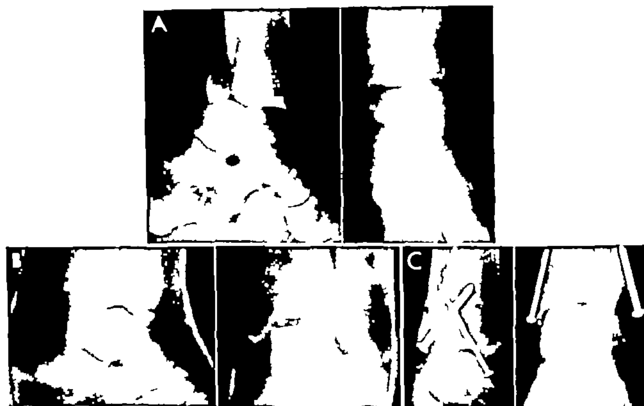


Fig 468 —An unstable fracture requiring more than minimal fixation A, bimalleolar frac ture-dislocation sustained in a fall off a bicycle The fragments are markedly comminuted and the chances of bone fragments remaining in the joint after reduction are good B postreduction views revealing the fragments in the joint. (These roentgenograms should have been taken before the cast was applied.) Loose bone fragments in the joint over weight bearing surfaces must be removed surgically C Internal fixation with 2 screws in the malleoli. At follow-up 1 year later there were a few symptoms but the patient was doing as much housework as formerly

medial malleolus in accurate alignment for weight bearing with the ankle mortise widened open reduction is advisable The interposition of periosteum and ligament tissue is a common finding at surgery A wide fracture line after closed reduction is an indication for operation. A position of good ankle function is more desirable than a strain position to hold reductions Therefore it is more advisable to do open reduc tions on malleolar fractures that lose posi tion than to do repeated manipulations (Fig 465)

Bimalleolar Fractures

With an intact tibial weight-bearing sur face it is possible to treat most ankle in juries by closed methods Pressure toward a bent knee through the intact concavity of the tibia from the sole of the foot held in slight equinus is the position of choice With the fingers locked behind the heel and the palms molded over the malleoli, the ankle may be rocked through a small arc of dorsal and plantar flexion to obtain a reduction The same procedure should be



Fig 469 —A definite indication for open reduction and internal fixation The surgeon may be tempted to leave this trimalleolar fracture (A anteroposterior and lateral views) as it is. However since the posterior tibial lip fracture involves about one half of the weight-bearing surface an effort should be made to get as anatomical a result as is possible B the position at tained by an attempt at closed reduction. It was decided to use the fractured medial malleolus in the surgical approach to the posterior lip fragment Through an anterior medial malleolar incision the malleolus was turned down at its fracture site and the tibial lip fragment line easily visualized This fragment was then anatomically replaced By the use of lag screws (C) the posterior lip fragment was held in place by turning the screw through a large hole in front to one of proper holding size behind This maneuver snugged the fragments into anatomical position The medial malleolus was then fixed with one screw A normally functioning ankle was obtained

used to mold the plaster casing which will have the contour of a normal foot and ankle The seating of the talus into the concavity of the tibia by pressure toward the knee will also prevent rotation deformi ties Keeping the foot in slight equinus will prevent the displacing effects of the tendon pulley forces on the malleoli The plaster should go above the knee which is flexed about 35 degrees

Tibial Weight Bearing Surface Fractures

Since most of these fractures have an intact talus the principle involved is that of using the talus to mold the fractured tibia. In all the groups of weight-bearing surface fractures the aim is to use trac tion to the point of slight distraction and then to mold the fragments against the talus If there is an intact weight bearing lip pressure toward such an area is kept while the plaster is applied. The molding of the fragments can be done with an elastic Esmarch bandage while traction is maintained Often the use of the hands alone is all that is necessary to obtain an excellent molding X ray films taken with this bandage in place will demonstrate the value of the molding

In anterior lip fractures with an intact posterior articular surface the foot is held in slight equinus while the molding is accomplished The ankle is then rocked through a safe arc of motion with pressure directed posteriorly so that a redislocation anteriorly will not displace the fragments The final position of forces is directed without strain toward the intact tibia in all tibial weight-bearing fractures

Early motion in comminuted articular surface fractures is essential Osteoplastic procedures to increase the range of motion are more successful after bone healing has taken place

Indication for Operative Treatment of Ankle Injuries

When a satisfactory reduction has not been maintained by a properly applied plaster casing open reduction is indicated A satisfactory reduction is one where the weight bearing surfaces and the malleoli are maintained in a functioning position Perfect alignment is of course desirable but is often unattainable even with open operations and so lack of a perfect reduction in itself is not sufficient reason for operation.

Open reductions are indicated whenever attempts at closed reduction have failed to produce realignment of the bone frag ments into acceptable positions of func tion (Figs 472–477) The most common reasons for open reduction are (1) failure to obtain good apposition of the medial

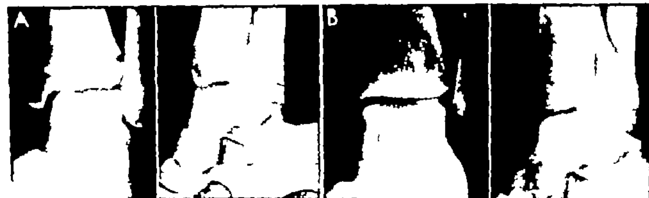


Fig 470 —A, anteroposterior and lateral views of a posterior tibial lip fracture the result of a twisting injury in an 11 year-old girl. Such a minimal epiphysial displacement seldom interferes with growth B 1 year later ankle now normal The patient had protection in plaster for 3 months

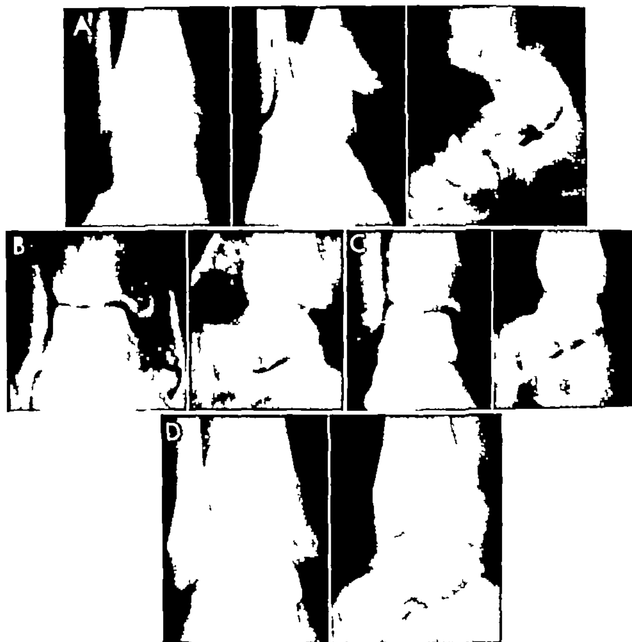


Fig 471 —Sudeck's atrophy following injury A, anteroposterior oblique and lateral views showing a severe dislocation from an external rotatory violence Note the fracture of the fibula and the marginal posterior lip fracture of the tibia B anteroposterior and lateral views showing reduction effected by careful manipulation of the reversal of the forces that produced the injury The posterior marginal fracture of the tibia does not involve articular surface C, the same views showing Sudeck's atrophy This amount of subchondral atrophy deserves supportive weight bearing until it disappears D 1 year after injury; anteroposterior and lateral views showing good articular margins and normal function the result of guided activities



Fig 472.—A simple fracture of the fibula which is allowed to heal in a slightly shortened position as this one has will continue to give symptoms Notice the tilted talus and asymmetry of the tibiotalus articulation At follow-up the ankle was continuing to swell and gave painful symptoms after a minimal amount of function



Fig 473 —A long intramedullary nail was used for fixation of this closed fracture of the fibula. The ankle was dislocated at the time of injury and was very unstable at closed reduction It lost position in the cast. At the end of 1 year the patient had symptoms of pain most of the time with swelling on increased function. Complete fibular length was not restored, evidenced *in these views*, by an upward tilt toward the fibula of the talar articular surface The first aim of fibular fracture is restoration of length the second a reduction of the rotatory element.

malleolus against the tibia (2) widening of the mortise in bimalleolar fractures (3) shortening of the fibula in a simple fibular fracture (4) inability to hold the fragment in its proper position (5) a displaced posterior lip equal to one fourth or

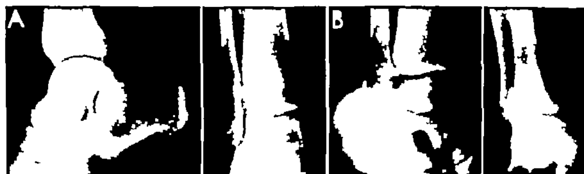


Fig 474 —A, lateral and anteroposterior views of an injured ankle in which the examiner had made a clinical diagnosis of a fractured fibula He ordered oblique views when the wet reading was reported "negative" for fracture B oblique view clearly showing the suspected fracture of the fibula (This view is obtained by having the lateral side of the foot rest on the plate) A walking plaster boot was applied

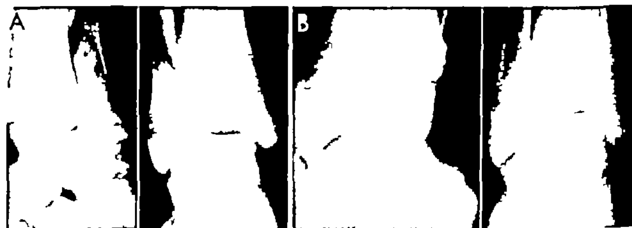


Fig 475 —A a fracture-dislocation the result of a twisting injury produced by a fall on ice Early weight bearing without support was allowed Such a disruption of a joint requires 8–12 weeks of plaster or brace support until the patient can walk normally without pain or swelling. B 1 year later more of an injury revealed than had been suspected The calcification below the medial malleolus is evidence of at least a partial tear of the deltoid ligament The patient still had symptoms and swelling after a few hours of work

more of the tibial articular surface which cannot be reduced by manipulation (6) anterior lip fractures which remain un reduced after manipulation and (7) the presence of intra articular fragments or ligaments which do not allow the talus to assume a good weight-bearing position under the tibia

Open Fractures

As mentioned before there is practically no spare skin around the ankle but skin closure without tension of the open ankle fracture is vitally important, even at the sacrifice of bone or with the addition of skin grafts If necessary osteoplastic changes can be made later

For internal fixation screws wire nails, or small plates of Vitallium or stainless steel may be used The stabilizing of one malleolus is often sufficient to hold the entire ankle Metal should be used spar

ingly To hold a separated tibiofibular ligament, a bolt or screw may be used as temporary fixture and removed in about 6 weeks If left in such a fixture may either break or become loose and impair ankle function.

Surgical approaches to the ankle should be as direct as possible and the incisions generally are better if they are slightly

from a simple bandage or adhesive strapping to non-weight bearing for as long as 12 weeks or more Each ankle injury is an individual problem Some ankle fractures may need brace support for many months

Simple malleolar fractures may be allowed to bear weight in plaster boots at 3–4 weeks and may need less protection for another 4 weeks—up to a total of 8



Fig 476 —A, a severe rotatory fracture with dislocation With this amount of lateral displacement the deltoid ligament would probably be ruptured An attempt at closed reduction (B) failed to reduce the ankle mortise to normal and the proximal fibula remained behind Operative treatment revealed the torn deltoid ligament, which was repaired A medullary nail in the fibula (C) was sufficient for stabilization Excellent function of the ankle joint resulted

curved at each end and bayonet shaped With such an incision there will be less tension on retraction and extension will be easier if the exposure needs enlarging The skin should not be devitalized by strenuous retraction

Length of Immobilization

Ankle injuries should be immobilized long enough to allow healing of sufficient strength to support the entire body The form of immobilization will of course vary with the type of injury or fracture—

weeks of support If the weight-bearing surfaces are intact, early weight bearing is an aid to function.

It is good practice to bivalve an ankle casing in 3–5 weeks and allow gentle active exercises for a few days before applying a walking cast for the remainder of the time needed for bone healing In severe ligamentous injury this is inadvisable

Management after Removal of Plaster Casing

The removal of a plaster casing from an injured ankle is followed by swelling and

the insecurity from the sudden loss of support is aggravated by muscle weakness A patient who has been walking about in a weight bearing plaster will after removal of the casing often suddenly have pain on walking and may need some support in the form of adhesive strapping elastic band and not involving a weight-bearing surface early weight bearing in a walking plaster boot is advisable A heel can be placed on the initial cast and weight bearing can be started as tolerated. Other types of fractures are protected from weight bearing until there is evidence of bone

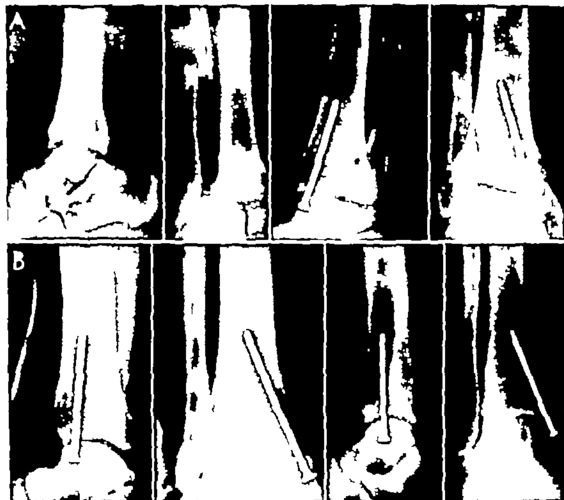


Fig 477 —A, a fracture-dislocation sustained when the patient was struck by an automobile Open reduction of the ankle joint alone was not sufficient to restore normal alignment in the ankle and pain persisted. The fibular fracture remained displaced and was over riding. Open reduction of the over riding transverse fractured fibula (B) restored the normal length of the fibula and resulted in a normal restoration of ankle joint alignment Pain was relieved

ages or an arch support Extensively injured ankles may require the support of a brace after the plaster is removed The brace should be made with double uprights with an ankle hinge and it should be fastened either to the heel of the shoe or into a sole plate (Fig. 478)

In fractures of the ankle involving only one malleolus and without displacement

union. No matter how favorable the fracture appears bone union must occur before complete weight bearing without support is allowed In fractures of the medial malleolus union takes place very slowly some type of support is necessary for 8–12 weeks

Bimalleolar and trimalleolar fractures with good reductions without surgery



Fig 478 —Aids in making a properly fitting ankle brace A weight bearing heel to be incor porated in a plaster boot should properly be positioned in line with the shafts of the tibia and fibula (A) This point is usually about at that area of the sole of the foot on which one has easy balance in a saddle stirrup To make a brace that will fit, a model of the foot and ankle should first be made (B); then the brace maker can make a plaster positive over which he can build a proper brace For the brace to function properly the amount of equinus should equal the height of the heel of the shoe C front and side views of two ankle braces The brace on the left in each illustration was used faithfully by a patient until a stable ankle was obtained as demonstrated clinically and by x ray The patient always had some pain while wearing this brace All the pain disappeared after its discard A study of the brace and the ankle revealed that the ankle joint was below the joint of the brace The brace on the right has its axis through the ra dius of motion of the talus This location of the brace joint is correct. Braces should be com fortable

should be protected for as long as 8 weeks in plaster and after that by adhesive strapping or a brace The duration of protection is dependent on the amount of soft tissue injury incurred at the time of the fracture A trimalleolar fracture which has been widely displaced certainly must have support for as long as 6–8 months after the injury appears to have healed The same fracture which has not been displaced and thus may be assumed to have had little soft tissue damage should be immobilized only until bone union has occurred.

Fractures involving weight bearing surfaces should be protected with some type of support for a period of 6–8 months as indicated by the reaction of the joint to function (Fig 478)

During the period of immobilization in plaster the patient should be seen at frequent intervals in order to assure the surgeon that the support is still performing its function The surgeon should not hesitate to change the plaster if it becomes loose At the time of the change of casing, the extremity should be treated with the same care that was used in the initial reduction.

After final removal of the plaster the excessive layers of skin are removed by washing the extremity several times during a 24–48-hour period Between washings the leg is protected from swelling by the application of an elastic bandage from the toes to the knee When the skin is relatively normal adhesive strapping can be applied to the ankle To control swelling, an elastic bandage may also be applied this should include the foot and leg The extremity is then protected by the use of either crutches or a cane until normal muscle strength has been recovered The patient is given exercises designed to increase ankle motion and muscle strength and to improve circulation in the extremity These exercises are active plantar flexion and dorsiflexion eversion and inversion heel cord stretching, and toe pressing They should be graduated from non-weight bearing to weight bearing Gait training is started early to prevent the development of a habit limp A Thomas heel with a slight inside wedge or an arch support may make the difference between a comfortable and an uncomfortable ankle. This simple program of renovation should be continued until muscle strength is adequate for the patient to carry himself up on his toes and back on his heels unsupported by the other foot. Occasionally the use of a stationary bicycle foot rockers and an inclined plane may be necessary in the rehabilitation program.

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30  Injuries of the Foot

ANATOMY

THE FOOT IS A complicated assembly of 28 bones which are held together by ligaments and activated by muscles A few of these muscles (the intrinsic muscles) are in the foot the others are in the leg Although roentgenograms taken after an injury may indicate the deformities of a fractured bone and the amount of displacement of the fragments reduction is facilitated by a knowledge of the ligamentous attachments and the directional force of the muscles. (See Fig 479 for the anatomy of the foot.)

There are three major arches in a normal human foot (1) the inner longitudinal arch (2) the outer longitudinal arch and (3) the anterior metatarsal arch

Three functions are performed by the bones of the human foot (1) weight bearing (2) locomotion and (3) shock absorption for the body For efficient performance of these functions following a fracture treatment demands restoration of the bones to as nearly normal integrity as possible

SOFT TISSUE INJURIES

Foot injuries vary in degree from a simple sprain or mild contusion to open comminuted fractures and dislocation A crushing or squeezing injury such as may occur when an automobile wheel runs over a foot on soft ground may not break the skin yet it can produce a severe injury to soft parts This has been called a "wringer foot" injury because the damage produced is similar to that caused by an automatic wringer on a washing machine when a person s fingers are caught and the hand is pulled through the rollers A "wringer foot" must be considered with even more concern than a "wringer hand" because of the foot s dependent position which can make the swelling worse

The immediate use of a compression bandage may prevent the woody edema and scar tissue formation which frequently limit early mobility and function. Inclusion of a foam-rubber sponge over the contused or crushed area will hasten the return to normal size

After 24 hours of gentle but effective compression over the entire foot (including the tips of the toes which may otherwise puff and become extremely painful) the bandages and sponges may be removed With the extremity elevated gentle massage from the toes toward the ankle may be started but heat must be omitted for the first 24-hour period

After 48 hours a little heat may be applied before or during massage The compression bandage should then be reapplied.

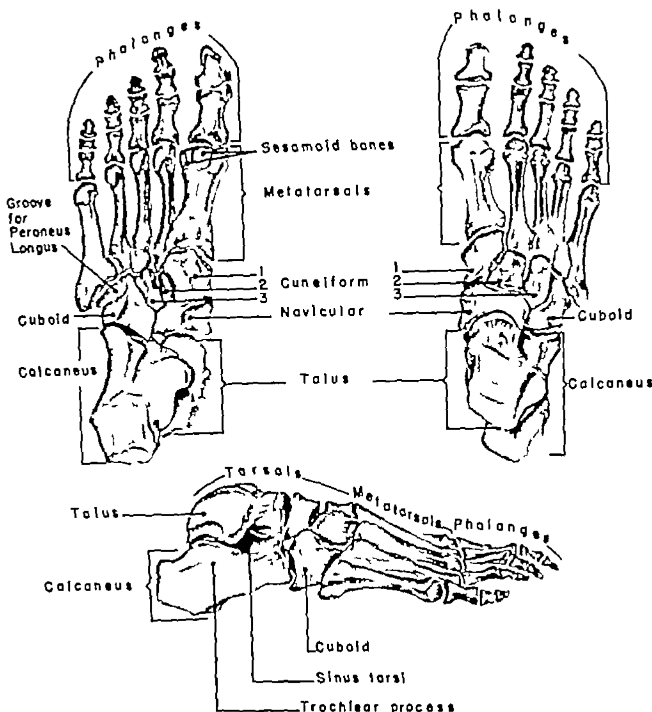


Fig 479 —Anatomy of the foot

Bed rest or the use of a wheel chair with the extremity elevated may be permitted as soon as the toes and forepart of the foot can be actively moved

Elevation must be regulated especially in the adult, because circulation can be diminished to the point of ischemia, which may lead to gangrene Children can tolerate more elevation than adults who probably should have the extremity kept at or near heart level

Berger exercises can be started early and continued as long as dependent edema is present. Partial weight bearing with crutches however may be permitted only when the dependent position can be tolerated In early convalescence putting the foot down causes rapid swelling and al

most instantaneously throbbing pain. Later in the period of convalescence these changes become less marked, and comfortable walking with crutches is possible

Once ambulation has begun the patient should be cautioned to avoid standing or sitting with the foot resting on the floor for prolonged periods When he sits on a chair his foot should be returned to the elevated position Exercises can be carried out satisfactorily with the shoe on

After a few weeks a standstill in convalescence may be observed and the patient may feel that normal recovery will never come This is the time to encourage walking to the point of pain, or even beyond to a mild degree the "pain barometer" being used as the ultimate guide It is advisable to force activity to the point of painful function each day If pain from activity has persisted throughout the night and into the following day then exercise has been overstressed if not activity should be continued Restoration of mobility of the joints of the foot and strengthening of muscular support are usually associated with diminishing pain

FRACTURES OF THE OS CALCIS

A review of 111 cases of fractures of the tarsal bones showed 67 fractures of the os calcis (calcaneus) Most of the os calcis fractures occurred in persons between their third and sixth decades with the peak incidence at 45 years (Fig. 480) It seems that these fractures occur more frequently in adult males who have reached an age at which their individual agility is lessened and their resistance to bone injury is decreased also that at this age the men are particularly exposed to industrial risk and accidents

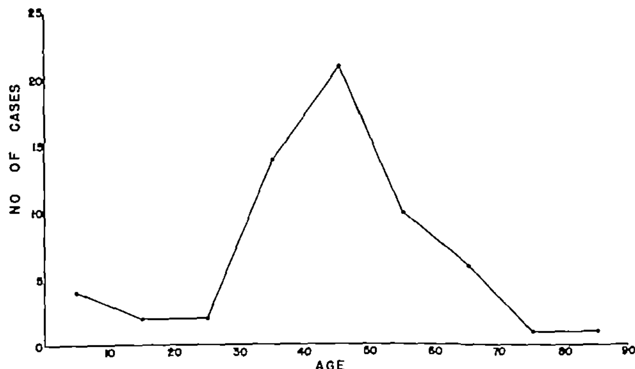


Fig 480 —Incidence of fractures of os calcis by decades

Of the 67 os calcis fractures 6 were bilateral and 1 was an open fracture—all in males In 5 cases (in males) there were complicating fractures of the spine an incidence of 7 per cent in the series

Types of Os Calcis Fractures

Os calcis fractures may be insignificant or very complex They may be divided into two general divisions those which do not enter the joint such as the chip or "beak"

and the avulsion types and those which involve the subtalar joint, the "crush" or comminuted type

Fractures of the posterior portion of the os calcis or tuberosity are usually the simplest type to treat. The fracture line may pass longitudinally through the bone from the back forward producing the so-called "split," "tongue" "duck bill" or avulsion be treated by open reduction and internal fixation as with a screw

A smaller linear fracture may occur in this region proximal to the attachment of the Achilles tendon (Fig 481 A) This also may be called a "duck bill" or "tongue" fracture the difference being only that the Achilles tendon is attached to the avulsed fragment in the avulsion type and not in

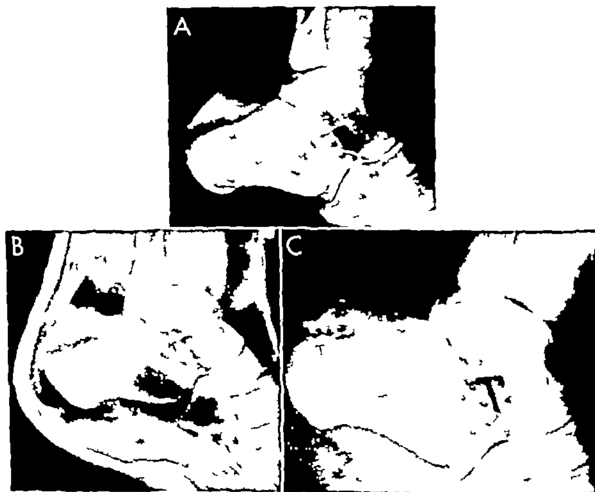


Fig 481 —Os calcis fracture ("duck bill" type) sustained when patient fell 4 feet striking her left foot on the floor *B* Immobilization in *plaster-of-paris boot.* *C* 5 months after injury gap in os calcis almost completely filled in.

fractures The avulsion or linear fracture where the Achilles tendon remains attached to the avulsed proximal fragment may be treated simply by closed reduction and plaster fixation with the foot in plantar flexion and the knee flexed or it may the other type Union of this type of fracture is facilitated by simple plaster fixation for about 4–6 weeks (Fig 481 *B* and C) with the foot in plantar flexion If reduction is then not satisfactory open reduction and internal fixation must be used

Fracture of the anterior process of the os calcis although rare is frequently overlooked Gellman believes because of the difficulty of diagnosis (Figs 482 and 483)

The normal adult gastrocnemius muscle may elongate as much as 10.5 cm. from the knee-flexion foot in equinus position to the knee-extended foot in dorsiflexion position.

most instantaneously throbbing pain Later in the period of convalescence these changes become less marked, and comfortable walking with crutches is possible

Once ambulation has begun the patient should be cautioned to avoid standing or sitting with the foot resting on the floor for prolonged periods When he sits on a chair his foot should be returned to the elevated position Exercises can be carried *out satisfactorily with the shoe on*

After a few weeks a standstill in convalescence may be observed and the patient may feel that normal recovery will *never* come This is the time to encourage walking to the point of pain or even beyond to a mild degree the "pain barometer" being used as the ultimate guide It is advisable to force activity to the point of painful function each day If pain from activity has persisted throughout the night and into the following day then exercise has been overstressed if not, activity should be continued Restoration of mobility of the joints of the foot and strengthening of muscular support are usually associated with diminishing pain

FRACTURES OF THE OS CALCIS

A review of 111 cases of fractures of the tarsal bones showed 67 fractures of the os calcis (calcaneus) Most of the os calcis fractures occurred in persons between their third and sixth decades with the peak incidence at 45 years (Fig 480) It seems that these fractures occur more frequently in adult males who have reached an age at *which their individual agility is lessened* and their resistance to bone injury is decreased also that at this age the men are particularly exposed to industrial risk and accidents

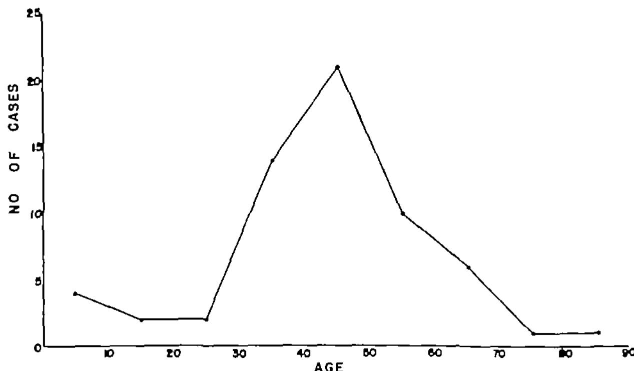


Fig 480 —Incidence of fractures of os calcis by decades

Of the 67 os calcis fractures 6 were bilateral and 1 was an open fracture—all in males In 5 cases (in males) there were complicating fractures of the spine an incidence of 7 per cent in the series

TYPES OF OS CALCIS FRACTURES

Os calcis fractures may be insignificant or very complex They may be divided into two general divisions those which do not enter the joint such as the chip or "beak"

and the avulsion types and those which involve the subtalar joint, the "crush" or comminuted type

Fractures of the posterior portion of the os calcis or tuberosity are usually the simplest type to treat The fracture line may pass longitudinally through the bone from the back forward producing the so-called "split" "tongue" "duck bill" or avulsion be treated by *open reduction and internal* fixation as with a screw

A smaller linear fracture may occur in this region proximal to the attachment of the Achilles tendon (Fig 481 *A*) This also may be called a "duck bill" or "tongue" fracture the difference being only that the Achilles tendon is attached to the avulsed *fragment in the avulsion type and not in*

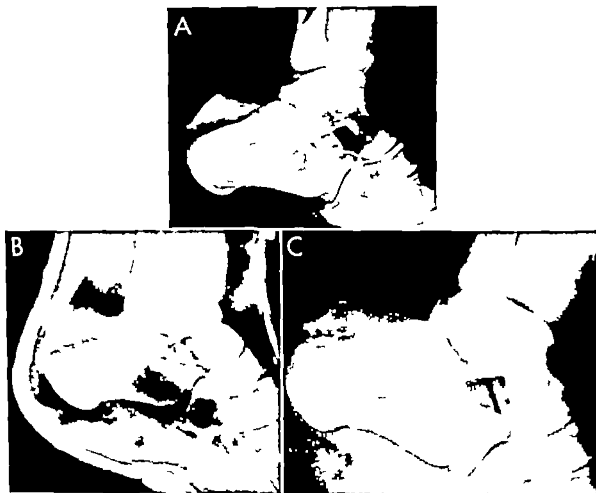


Fig 481 —Os calcis fracture ("duck bill" type) sustained *when patient fell 4 feet, striking* her left foot on the floor B Immobilization in plaster-of paris boot. C 5 months after injury gap in os calcis almost completely filled in

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Fracture of the anterior process of the os calcis although rare is frequently overlooked *Gellman believes because of the* difficulty of diagnosis (Figs 482 and 483)

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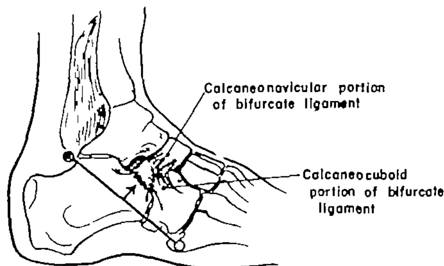


Fig 482.—Schematic drawing demonstrating how the bifurcate ligament avulses the anterior process of the calcaneus when the foot is sharply inverted If a line drawn from the tip of the external malleolus to the tip of the base of the fifth metatarsal bone (usually a distance of 3 inches) is bisected by a perpendicular line projected toward the top of the tarsus the point of maximum tenderness will be found. (From Gellman, M.: Fractures of the anterior process of calcaneum J Bone & Joint Surg. 33-A 382, 1951)

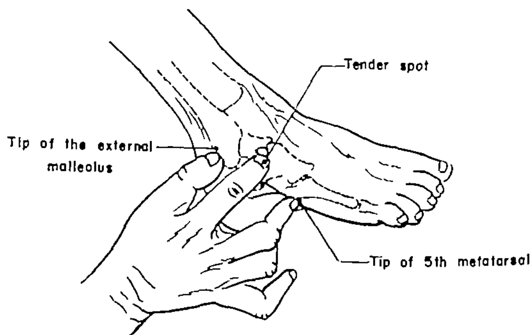


Fig 483 —Technique for diagnosing fracture of anterior process of os calcis If the examiner places his thumb on the tip of the external malleolus and the middle finger on the tip of the base of the fifth metatarsal bone the slightly crooked index finger held equidistant between these two bones will fall directly on an exquisitely tender point. (From Gellman, M Fractures of the anterior process of calcaneum J Bone & Joint Surg. 33-A 382, 1951)

and the failure to show the fracture clearly by roentgenograms Since the mechanism of fracture is probably forceful adduction of the forepart of the foot or forceful ex tension (as when a person catches the viewed there were 3 fractures of the ante-rior process In 2 cases the small fractured portion was excised (Fig 484) because of delayed union and malposition In these 2 patients pain persisted for about 6 months



Fig 484 —Left, fractured os calcis (anterior process) of left foot (*arrow*) sustained when patient fell off a chair while hanging curtains Treatment consisted of the excision of anterior process of the os calcis followed by plaster casing Right 2¼ years postoperatively A small bone fragment has re-formed (*arrow*)

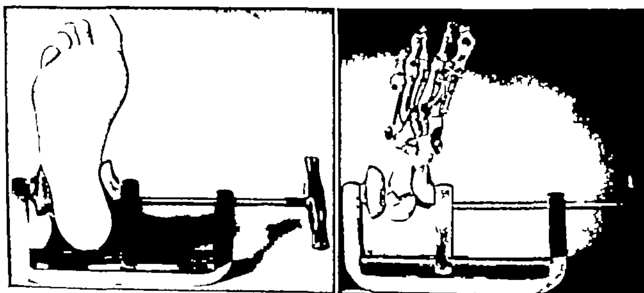


Fig. 485 —Left Böhler clamp applied to foot. Right same apparatus used on skeleton of foot, demonstrating correct position of pressure knobs

forepart of his foot in a hole and falls backward) treatment may require a plas ter-of-paris boot as described by Bradford with the foot in slight valgus and dorsi flexion to appose the fragments and reduce the tension on the bifurcate ligament

Of the 67 cases of os calcis fractures re probably as a result of associated injuries to the subastragalar joint. Therefore it is believed that operative removal is not the method of choice plaster fixation should certainly be tried first and excision re served as a last resort

From both the clinical and the economic

aspects the os calcis is the most important bone in the foot. Not only is it the largest bone in the foot but it is the one most frequently fractured and the one which causes the longest period of disability Geckeler reported in 1950 that an orthopaedic consultant to an insurance company found from a review of 100 cases that the average time lost from work after a comminuted os calcis fracture amounted to 18 months plus $1 561 paid in compensation Furthermore he stated that there was a decided permanent disability in almost every instance

Serious efforts to restore the comminuted fractured os calcis to its normal anatomical configuration were started only relatively recently Cotton of Boston pioneered the way in 1908 by introducing the technique of disimpaction and molding the fragments with a mallet. A rapid series of reports on the technique followed in surgical journals Enthusiasm increased with continued improvement in technique both for anatomical restoration and for early rehabilitation.

Similar techniques were used in clinics both in the United States and abroad Böhler used a clamp for compressing the lateral bulging deformity (Fig 485) Harris devised an adjustable circular apparatus which could produce skeletal traction on the fragments in three different directions But unfortunately accurate anatomical reposition of the fragments was not the whole answer Triradiate traction restored the alignment beautifully but not the blood supply The resulting aseptic necrosis required different treatment Harris then advocated subtalar arthrodesis after the technique of Gallie Conn introduced a less cumbersome reduction apparatus for the "squash" type of fractures and advocated 5 weeks traction followed by a triple arthrodesis—still more surgery Thus the pendulum had swung too far Not only did the use of such cumbersome apparatus and subsequent operations keep the patient in the hospital for too long a period but the expense became prohibitive Furthermore the result was frequently a deformed immobile foot. In the search for a simpler method Ivar Palmer suggested early open reduction with bone graft.

Mechanism of Fracture

When a person falls from a height and lands directly on his heels or when an explosion beneath the deck of a ship suddenly produces an impact from below the result is the same two opposing forces one transmitted through the tibia and the other from beneath the os calcis cause the talus to be driven into the os calcis The lateral wall of the os calcis is broken off the medial wall with the sustentaculum tali may or may not be broken away and driven downward. The middle portion of the bone with its lateral fragment may be displaced laterally and appear as a hard mass below the lateral malleolus

Furthermore the tuberosity may be divided longitudinally producing broadening The normal tuber joint angle (salient angle) of about 40 degrees may be lessened or even reversed (Fig 486)

Conservative Treatment

Most of the cases of os calcis crush fractures that have been reviewed were treated by the so-called conservative method of manual molding of the os calcis and the application of a plaster-of paris boot or long leg casing with the knee slightly flexed (Fig 487) For this treatment the patient's knee is flexed over the end of the operating table With the operator seated in front of the patient, the os calcis can be compressed through the "heels" of the operator's hands With his fingers clasped the operator catches the heel in this "manual vise" and applies pressure with traction until the impaction is broken up and the deformity corrected. A helpful trick is to apply liquid adhesive to the patient's heel and the operator's palms before the procedure is carried out much more traction can then be applied Next

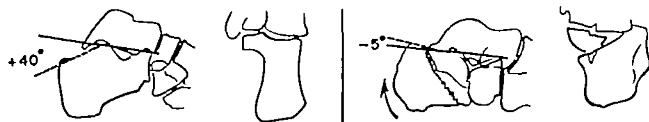


Fig 486 —Left normal foot showing the tuber joint angle Right comminuted fracture with displacement of outer part of posterior joint demonstrating reversal of tuber joint angle (From Watson Jones R. *Fractures and Joint Injuries* [3d ed Baltimore Williams & Wilkins Company 1943])

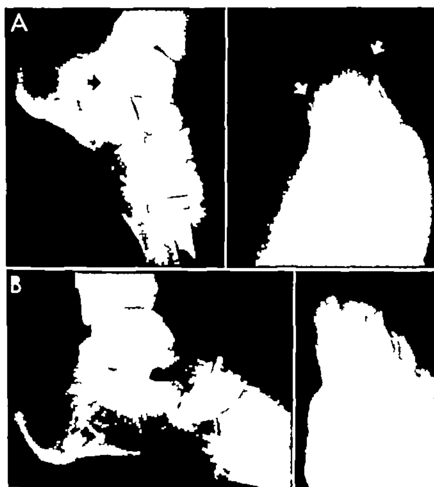


Fig 487 —A, lateral and heel views of fractured os calcis (*arrows*) Treatment required little manual molding and the application of a plaster casing for 4 months B 2 years later excellent result ($E_1F_4A_1$)

felt rolls are placed carefully beneath each malleolus and plaster casing is applied The casing is changed in a week or two if it becomes loose and a snugly fitting plaster is kept on until healing has occurred After 4–6 weeks a walking heel is applied for partial weight bearing

Operative Treatment

The "squash" type of comminuted os calcis fracture with its broadening shortening and compression of the os calcis is considered the worst type from the standpoints of both reduction and rehabilita

tion The treatment of these fractures by the method of Ivar Palmer gives good results (Figs 488 and 489) His technique can restore the tuber joint angle as well as correct the other deformities (Fig 490) The best results can be expected when the articular facets are not fractured or destroyed If the facets are badly damaged the prognosis is poor and the possibility of a subtalar arthrodesis or triple arthrodesis should be considered

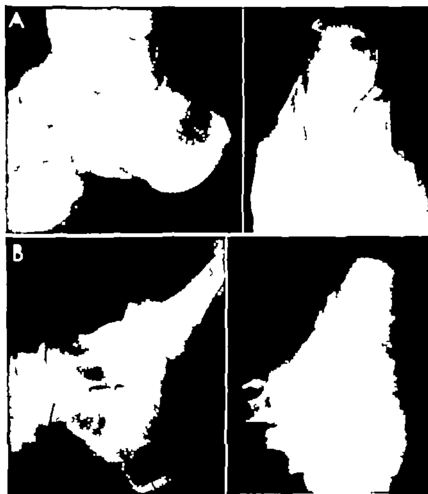


Fig 488 —A lateral and posterior views of fractured right os calcis Treatment by Palmer technique with bone graft followed by 8 weeks in a plaster casing Patient was back at work in 8 additional weeks B 1½ years postoperatively excellent result ($E_1F_4A_1$)

Postoperative treatment for the Palmer procedure consists of a long plaster-of-paris casing for 4–6 weeks depending on the weight of the patient For example a 200-pound man may be kept in plaster 6 weeks a lighter person, only 4 weeks At the end of this period the plaster is cut below the knee and the patient begins partial weight bearing with crutches and with a rubber heel attached to the bottom of the boot. At the end of 4 weeks the casing is removed and a roentgenogram is made If consolidation is apparent, the patient is permitted to start wearing his shoe with a molded steel arch support.

Of 14 cases treated by this method 10 have been followed and rated. The end-result ratings (according to the method of rating described in Chapter 2) were

$E_1F_4A_1$	4*	$E_3F_3A_3$	2
$E_1F_4A_3$	1	$E_0F_3A_3$	1
$E_1F_3A_3$	2		

* One patient was over 60 years of age.

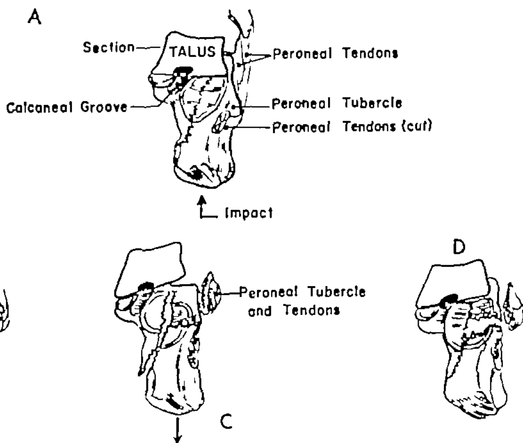


Fig 489 —Deformities of fractured os calcis reduced and maintained by bone graft (after Palmer) A, position before displacement of fragments B immediate result after impact. C position after traction D reposition after open reduction, demonstrating open space for insertion of bone graft.



Fig. 490 —Deformities of fractured os calcis reduced and maintained by bone graft (after Palmer) A, the step in the joint (right calcaneus) B after reduction of lateral fragment C, bone graft inserted

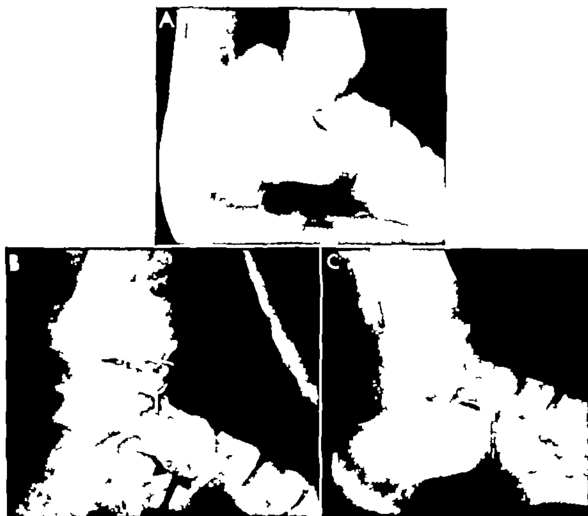


Fig 492.—A, fractured left talus with dislocation sustained in an automobile accident B after treatment by open reduction and a wire loop in the medial malleolus C 4 months post operatively indicating nonunion with aseptic necrosis Rating 2 years postoperatively failure ($E_0F_0A_0$)

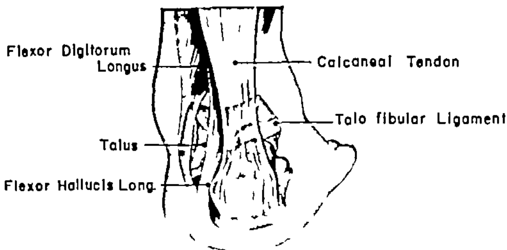


Fig 493 —Diagram showing buttonhole formed by flexor digitorum longus and flexor hallucis longus through which talus may be squeezed in posterior dislocation with shutting-off of its blood supply (Gibson A and Inkster R. C Fractures of the talus Canad M A J 31 357 1934)

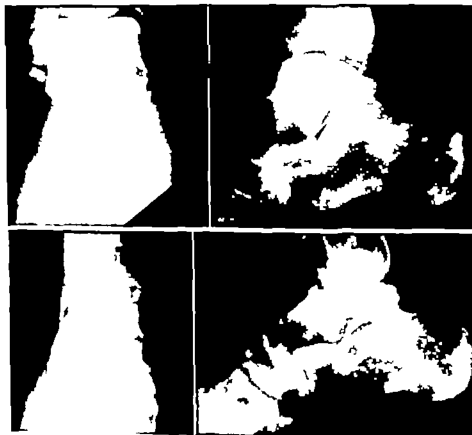


Fig 494 —Top anteroposterior and lateral views of right foot showing aseptic necrosis 5 months after fracture through neck and body of the talus Bottom 3 years after injury showing fusion following tibiotalar arthrodesis

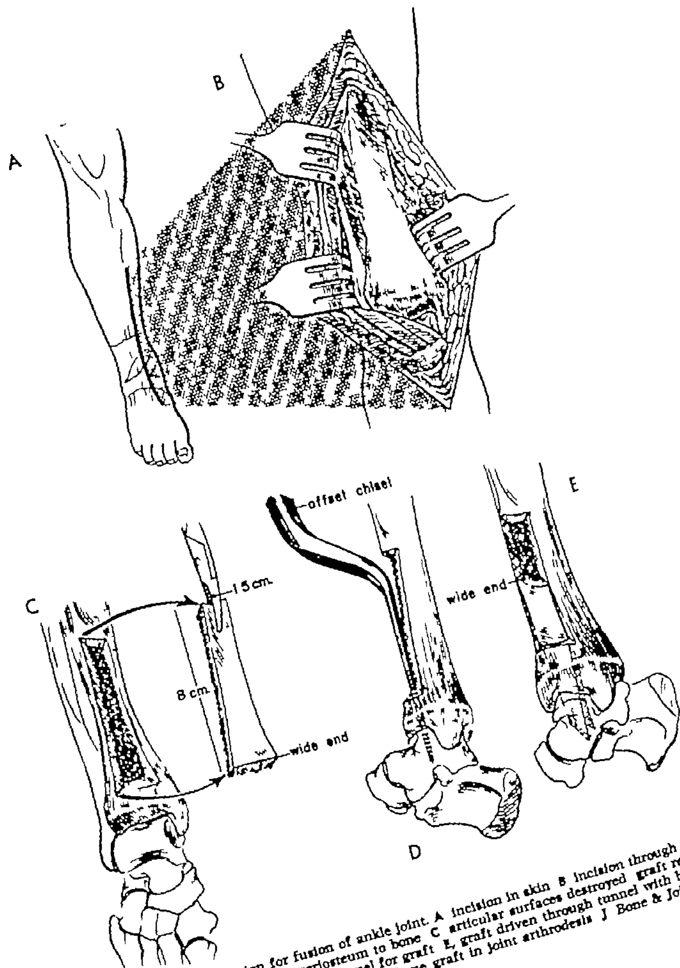


Fig 493 —Operation for fusion of ankle joint. A incision in skin B incision through the anterior tibial sheath and the periosteum to bone C articular surfaces destroyed graft removed D bayonet-type osteotome forms tunnel for graft E, graft driven through tunnel with bone set (Adapted from Hatt R N The central bone graft in joint arthrodesis J Bone & Joint Surg. 22 393 1940)









Fig 496 —A, lateral view of comminuted open fracture of posterior third of talus (left foot) with complete detachment of this portion of bone from the remainder B after excision of talus. Arthrodesis was performed 1½ years later C anteroposterior and lateral views 6 months after arthrodesis.

cise the talus and then later perform an arthrodesis of the tibia to the os calcis if painful function demands it (Fig. 496)

FRACTURES OF THE TARSAL NAVICULAR

There are three different types of navic ular fractures fracture of the tuberosity fracture of the dorsal lip and transverse fracture of the tarsal navicular

Fracture of the tuberosity is usually an avulsion fracture caused by the pull of the posterior tibial tendon This tendon has such a broad distribution that it is impos sible for the fragments of bone to become widely separated. Treatment for this type of fracture consists of wearing a plaster of-paris boot for 8–10 weeks Recovery of function is usually good.

In fracture of the dorsal lip ordinarily only a piece of bone is flaked off Immobilization in plaster or by adhesive strapping for 3 weeks usually gives excellent results.

The transverse fracture of the tarsal navicular is a different matter (Fig 497) In this fracture there usually is a large dorsal and a small plantar fragment. If displaced the dorsal fragment may be replaced by pressure of the thumb and held by a plaster casing but displacement is likely to recur No matter what the treat ment, the fragmented bone may undergo absorption, with resulting arthritis and prolonged disability until dense fibrous union appears Therefore immediate ar

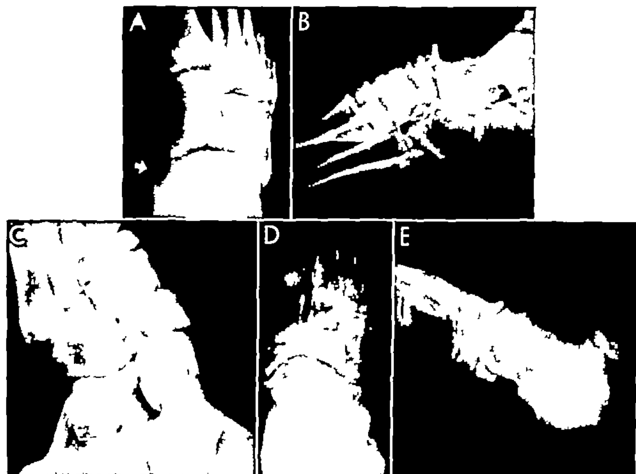


Fig 497 —A and B anteroposterior and lateral views of compression fracture of tarsal na vicular bone (*arrow*) C lateral view after closed reduction. D and E anteroposterior and lat eral views 2 years after injury showing aseptic necrosis of navicular bone and traumatic arthritis

throdesis of both the talonavicular and navicular-cuneiform joints with a tibial graft laid in a trough and immobilized in plaster for 10 weeks is considered the best and safest treatment *Other methods how ever* such as wiring fragments together have been successful If the dorsal frag ment is not displaced transverse fractures may be successfully treated by plaster fixa tion for 4 weeks and later an arch support

The proximal end of the fifth metatarsal may be injured by turning the foot inward and placing pressure on the proximal en larged portion of the bone The force from *the impact with the pavement* or other firm surface together with the increased pull of the peroneus brevis tendon may produce a fracture Usually only slight separation of the fragments occurs Treat ment by simple adhesive strapping and

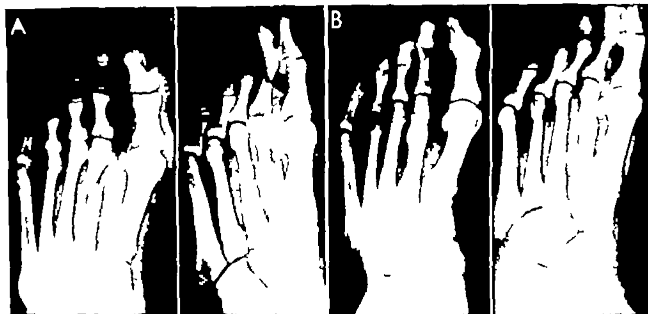


Fig 498 —A, anteroposterior and oblique views of complete transverse comminuted fracture of left second metatarsal Treatment by closed reduction (apposition not complete) and plaster casing. B 1 *year after injury excellent result* ($E_1F_4A_4$)

METATARSAL FRACTURES

Metatarsal fractures such as strain fa tigue or march fractures first described by Breithaupt in 1855 may not be seen in early x ray films but several weeks later repeat films will show the fractures clearly In treating severe metatarsal strain frac tures bed rest may be necessary for a while The usual regimen is plaster casing for 3 weeks followed by the use of a care- fully molded steel arch support.

A fracture of the neck of the metatarsal demands careful replacement or a painful plantar callus may develop *All displaced* metatarsal fractures should be corrected in particular the dorsal bow of the meta tarsal should be restored (Fig 498)

arch support may be adequate in undis placed fractures (Fig 499) but if there is marked deformity then eversion of the foot, replacement of the displaced frag ment by firm digital pressure and im mobilization by a plaster boot may be indicated

A review of 40 cases of metatarsal frac tures revealed that of the 34 in which end results were available results were excel lent in 26 cases or 75 per cent

METATARSAL FRACTURES WITH TARSOMETATARSAL DISLOCATIONS

If displacement is not severe a satisfac tory foot usually results from the reduction (open or closed) and molding of the dis-



Fig. 499 —**Left** oblique view of fractured proximal end of the left fifth metatarsal sustained when patient twisted her foot while walking. Treatment by strapping for 1 month. **Right** 1 year later excellent result ($E_4F_4A_4$)



Fig 500 —**A**, anteroposterior and lateral views of tarsometatarsal dislocation sustained in an automobile accident There were fractures of the second third fourth and fifth metatarsals, of the second and third cuneiform, and of the cuboid. Treatment by open reduction and wire fixation and a plaster boot. Patient returned to her job as secretary 8 weeks after operation. **B** 9 months postoperative satisfactory result.

placed parts as accurately as possible even though exact anatomical restitution may be impossible (Fig. 500) This procedure is followed by immobilization in a plaster of-paris boot for 6–8 weeks with partial weight bearing on crutches permitted after the fourth week. At the outset it is impera tive that the patient keep the foot elevated and do active exercises in order to avoid undue swelling Improvement may con tinue over a period of 2–3 years if the pa tient wears a suitable shoe with arch support and elastic anklet and continues active exercises

Falling objects frequently and perhaps unnecessarily cause fractures of the meta tarsals The conscientious use of steel toe-protector shoes which many industries require of their workers has lessened the incidence of these fractures considerably A typical example of such an injury fol lows

A steelworker was standing on the ground when a strip of steel fell from a height of 5–6 stories It missed his head by only a fraction of an inch and struck his second and third toes near the junction with the foot causing open fracture-dislocation of the second and third toes sever ing all blood and nerve supply and leaving *the toes attached by a small piece of skin* with insufficient blood supply (Fig 501 *left*) Although the patient was seen approximately 1 hour after the injury the second and third toes were cold and avascular and no blanching could be demon strated on any portion of either toe Imme diate amputation and closure of the skin were done after debridement of the meta tarsal heads Nevertheless continued for mation of painful neuromas on the dorsum of the foot eventually demanded further plastic surgery consisting of the excision of most of the second metatarsal and a mass of scar tissue comprised of tendons nerves and blood vessels (Fig 501 *right*) Following this procedure the patient remained asymptomatic and he returned to work about 8½ months after injury



Fig 501 —**Left** open fracture dislocation of second and third toes Treatment by amputation followed by plastic surgery **Right** 7 months after injury

PHALANGEAL FRACTURES

Phalangeal fractures may be caused by objects falling on the toes or by the stub-

bing of toes while walking barefoot. Diag nosis and treatment are usually easy

If only a single phalanx is fractured there is normally no disability If the fifth toe is fractured it may be wise to strap this toe to the adjacent one in order to prevent continual displacement at night and during bathing, when the shoe is removed Usually the wearing of the stocking and shoe provides adequate protection A Jones bar ½ inch wide and ¼ inch high placed diagonally across the sole of the shoe just proximal to the metatarsal head or a steel plate inserted between the layers of leather in the sole effectively prevents painful motion of the toes during walking Phalangeal fractures are usually asymptomatic after 6 weeks but the fracture line may be clearly visible in x ray films for 6 months to a year

Simple fracture of the phalanges may be quite disabling when multiple but if the toes are carefully protected by bits of foam rubber or felt on the plantar surface and strapped one to the other with cotton or gauze between them to prevent mascera tion no disability need be experienced Treatment should be directed toward avoiding hammer-toe deformity rotation deformity or lateral deviation The sooner a shoe can be worn the quicker the bones will be molded to a functional position If one of the lesser toes is fractured disabil ity lasts for 2–3 weeks in the case of the great toe 4–5 weeks

Open fractures of toes require debridement antitoxin chemotherapy and repair of tendons and if the blood supply of the toe is imperiled amputation may be necessary Deformity may be prevented by skele tal traction by a needle in the terminal phalanx (not in the soft tissue) or by a Kirschner wire threaded down through the phalanges

Caution must be exercised in cases of open fracture At the Fracture Clinic of the Massachusetts General Hospital 2 cases of fracture of the foot each produced by an ax cutting through the shoe into the great toe resulted in lockjaw with 1 pa tient succumbing

In a review of a series of phalangeal fractures end results were available in only 16 cases In 11 of these 16 (almost 70 per cent) the results were excellent ($E_1F_1A_1$)

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31  Epiphysial Injuries

EPIPHYSIAL STRUCTURES

FRACTURES OF THE EPIPHYSES are among the commonest injuries of childhood The parts of the body most frequently injured are the wrist ankle and elbow because of their anatomical location and the construction of the joints Active children at play fall frequently landing on their wrists or elbows or they twist their ankles

The epiphyses in the freely movable joints such as the shoulder are less likely to be injured than are those in a firmly held joint, such as the ankle The larger the size and irregularity of the epiphysis (for example the distal end of the femur) the greater the force or trauma required to injure or fracture Consequently the epiphyses of the firmly held joints are more likely to be seriously damaged

The age of the patient is an important consideration The older the child, the slower the growth of the epiphysis and the less likelihood that the epiphysis will slip under strain. The height of the child also affects the incidence of injuries the longer the bones the longer the lever arms and the greater the amount of force that can be exerted (For the time of appearance and of ossification of epiphyses see Table 20)

*[Although epiphysial injuries are discussed elsewhere in this volume with particular reference to various individual bones, it seems worth while to include a separate chapter on the general subject of trauma to the epiphyses and results therefrom.—ED]

TABLE 20 —TIME OF APPEARANCE AND OF OSSIFICATION OF EPIPHYSES*

EPIPHYSES	APPEARANCE	AGE AT COMPLETE OSSIFICATION
Upper humerus	At 7 weeks	18–20 years
Internal epicondyle of humerus	As early as 7 years not constantly present until 11 years	15–17 years
External epicondyle of humerus	Not ordinarily as separate epiphysis	15–17 years
Capitellum	At 17 months	15–17 years
Trochlea humeri	As early as 8 years; not constantly present until 11 years	15–17 years
Head of radius	Occasionally at 5 years; constant at 7 years	13–14 years
Olecranon	At 8 years	14 years
Distal radius	At 6 months	20–21 years
Distal ulna	At 6–7 years	20–21 years
Head of femur	At 7–12 months	15–18 years
Greater trochanter	At 5 years	15–18 years
Lesser trochanter	At 9–11 years	15–16 years
Distal femur	Present at birth	19 years
Proximal tibia	Present at birth	19 years
Distal tibia	At 5 months	18 years
Proximal fibula	At about 5 years	15–18 years
Distal fibula	At 13 months	18 years

* From Cohn, I : *Normal Bones and Joints* (New York Paul B. Hoeber Inc., 1924)

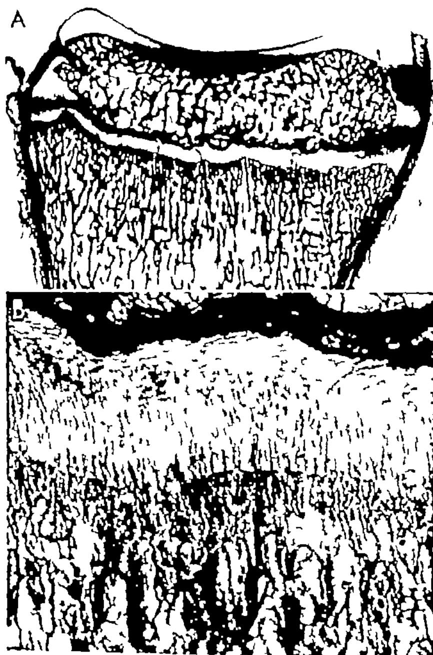


Fig 502.—A, anteroposterior cross-section of proximal tibial epiphysis of child aged 12. B higher magnification showing parallel columns of proliferating and degenerating cartilage cells at the so-called zone of most rapid growth and weakest structure " The zone of calcification is also seen

The weight bearing joints are more vulnerable than the non-weight bearing joints and the active athletic child naturally receives more injuries than does the quiet inactive one Acceleration of growth is extremely important since the rapidly growing zone of the epiphysis is the weakest part of the entire structure of the bone (Fig 502)

EPIPHYSIAL FRACTURES

The usual types of epiphysial fractures as described by Aitken are shown in Figure 503 Although it is impractical to give a description of every epiphysis which can be injured in the growing child a few examples of the ones that are most frequently damaged can be given The principles of



31 Epiphysial Injuries

EPIPHYSIAL STRUCTURES

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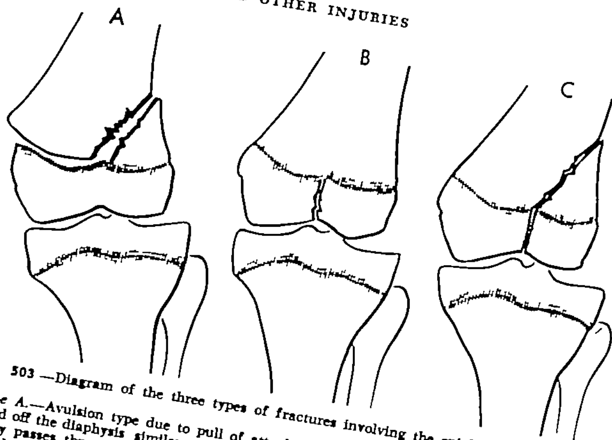


Fig 503 —Diagram of the three types of fractures involving the epiphysial cartilaginous plate

Type A.—Avulsion type due to pull of attached ligaments The entire epiphysial plate is stripped off the diaphysis similar to the stripping of a layer of plywood. The fracture line apparently passes through the zone of degenerating cartilage cells osteoid tissue and newly formed bone Displacement may be marked but ultimate deformity due to the displacement or to growth disturbance is rare The forces of stress and strain (acting according to Wolff's law) ultimately restore the normal shape of the bone once union of the diaphysis to the epiphysis has occurred Reasonable apposition at reduction is essential In complete anterior displacement, with the epiphysis lying at right angles to its normal position nature cannot restore the bone to normal because once the epiphysis has rotated through such a wide arc correcting forces acting on the epiphysis no longer operate

Type B —Compression type of fracture commonly involving the distal tibial epiphysis but rarely the distal femoral epiphysis The fracture line may emerge between the bony epiphysis and the epiphysial plate without damage to the latter in such a case growth disturbance will not occur If however the fracture line crosses the plate and emerges between it and the diaphysis then deformity will occur

Type C —Compression type of injury in which the epiphysial plate has been crushed between the bony epiphysis and the diaphysis In this injury deformity is to be anticipated. The fracture line need not be so extensive as that shown in the drawing it may involve only a small area of bone on either side of the epiphysial plate or it may be so small as to be overlooked or to be considered as of no clinical or roentgenological significance

treatment which are demonstrated in these individual examples apply equally well to all

Distal Radial Epiphysis

The distal radial epiphysis appears at 6 months and fuses with the shaft in the twentieth or twenty first year This epiphysis is injured more frequently than any other because of the frequency with which children fall on their outstretched hands Although fractures of this epiphysis occur during the ages of 4–18 years (Fig. 504) they are sustained most frequently between the ages of 10 and 16 years The growth of the radius is largely derived from its distal end (Fig. 505) relatively little growth (about 10 per cent) takes place at the proximal end. All epiphyses unite slightly earlier in the female than in the male

Crushing injuries are relatively uncom-

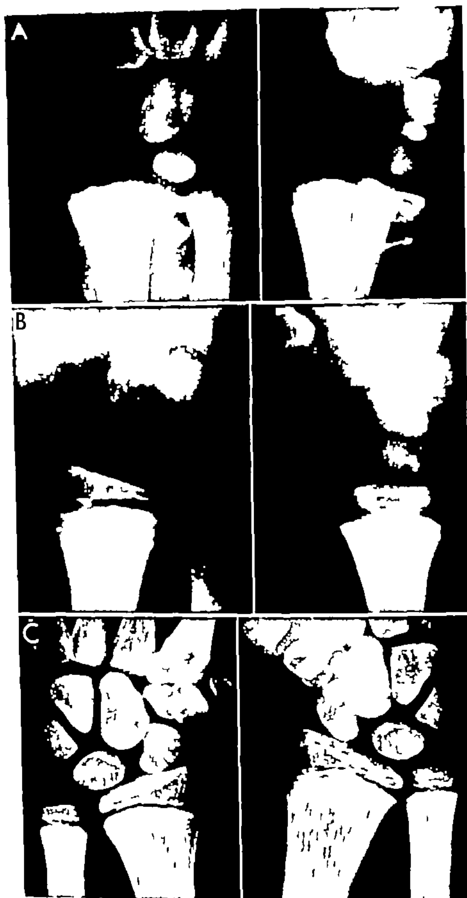


Fig 504 —A, anteroposterior and lateral views of separation of distal radial epiphysis in boy aged 6 B immediately after closed reduction C anteroposterior views of both wrists 4 years later minimal growth retardation in right radius

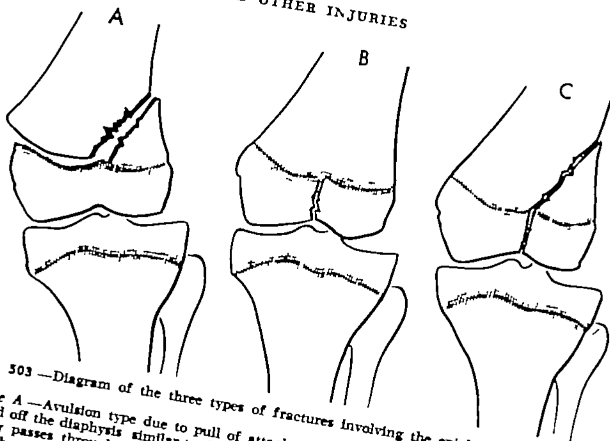


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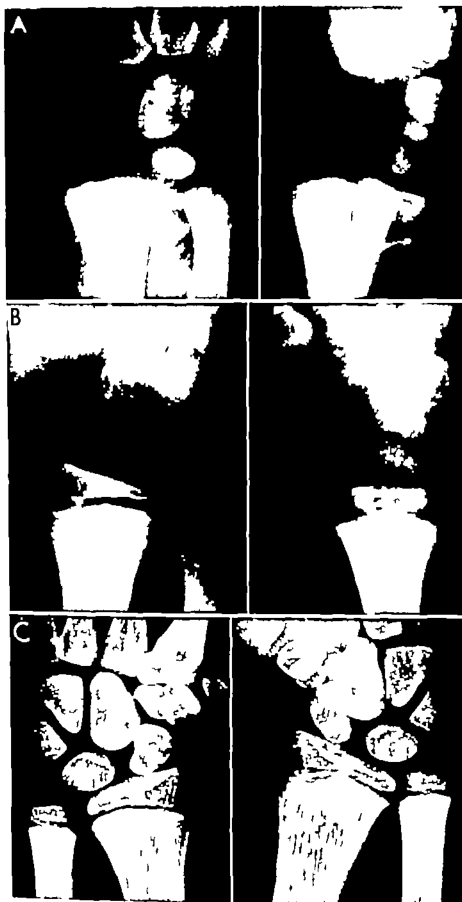


Fig 504 —A anteroposterior and lateral views of separation of distal radial epiphysis in boy aged 6 B immediately after closed reduction C anteroposterior views of both wrists 4 years later minimal growth retardation in right radius

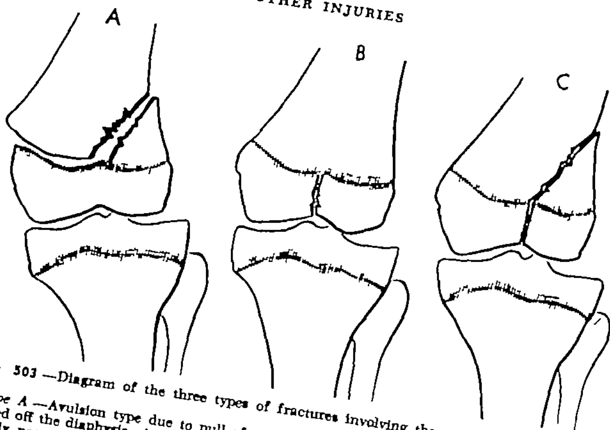


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Distal Radial Epiphysis

The distal radial epiphysis appears at 8 months and fuses with the shaft in the twentieth or twenty first year This epiphysis is injured more frequently than any other because of the frequency with which children fall on their outstretched hands. Although fractures of this epiphysis occur during the ages of 4–18 years (Fig. 504) they are sustained most frequently between the ages of 10 and 16 years The growth of the radius is largely derived from its distal end (Fig. 505) relatively little growth (about 10 per cent) takes place at the proximal end All epiphyses unite slightly earlier in the female than in the male

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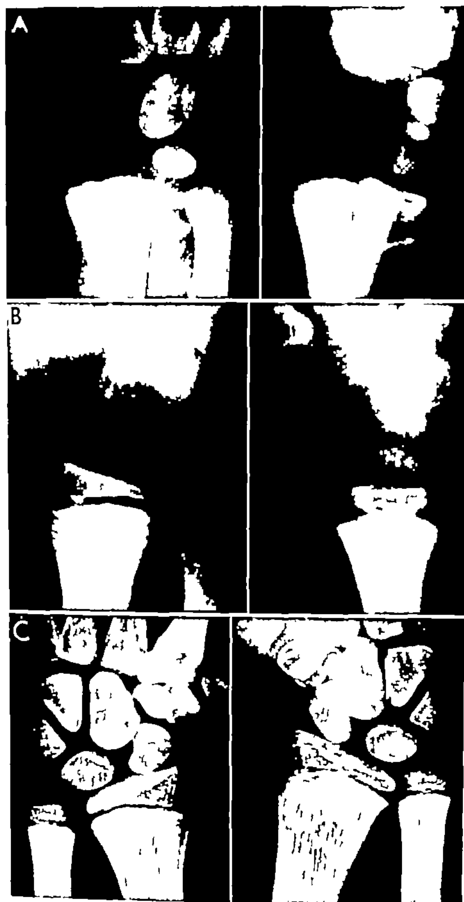


Fig 504 —A, anteroposterior and lateral views of separation of distal radial epiphysis in boy aged 6 B immediately after closed reduction C anteroposterior views of both wrists 4 years later minimal growth retardation in right radius

mon in this region although they do occur A fracture of the ulnar styloid or a chip from the metaphysis is commonly associated with fractures of the distal radial epiphysis

In treating a fresh fracture the operator should gently attempt to reduce the displaced epiphysis If the fracture is more than 1 week old and the patient is 13 years of age or less the surgeon may decide not to manipulate because of possible trauma to the epiphysis If the patient is 14 years of age or older reduction by gentle manipulation should be tried In the younger age group nature corrects the displacement and heals the gap (even though the gap extends almost across the full thickness of the shaft of the radius) and remolds the steplike deformity The remolding appears in the roentgenogram as if a sleeve of periosteum accompanied the displaced epiphysis This sleeve appears to split, thus The resulting deformity is minimal. Open reduction should not be done unless the epiphysis is completely stripped off and displaced dorsally on the shaft of the bone and cannot be replaced by manipulation Postreduction immobilization is carried out for 3–4 weeks at the end of which time the replaced epiphysis is stable

The statistics regarding the end results in distal radial epiphysial injuries at the Massachusetts General Hospital over a period of 17 years are as follows

Total number of cases treated	85 (100%)
Excellent results	78 (92%)
Less than excellent results	7 (8%)
Of the cases rated less than excellent (8% of total)	
Results by open reduction	Poor
Results by closed reduction	Good

DISTAL PHYSIS



Fig 505 —Anteroposterior and lateral views before and after excision of distal end of ulna in a 15-year-old boy who injured the radial epiphysis in a sledding accident 5 years earlier creating an arrest of growth of the radial epiphysis The distal ulnar epiphysis continued to grow causing painful deviation of the hand. To relieve pain and restore normal position of hand the distal portion of the ulna was surgically removed.

physial cartilage lies at right angles to the long axis of the shaft of the ulna and supplies growth for nearly all of the length of the ulna

Since the distal ulnar epiphysis does not appear before the sixth or seventh year a diagnosis of fracture of this epiphysis can not be made in the very young

Although the displaced epiphysis should be replaced as accurately as possible when treating a fracture the epiphysis must be handled gently since after crushing in juries it unites early Too early union not only causes the ulna to become much shorter than the radius but bowing of the radius occurs resulting in displacement of the hand to the ulnar side

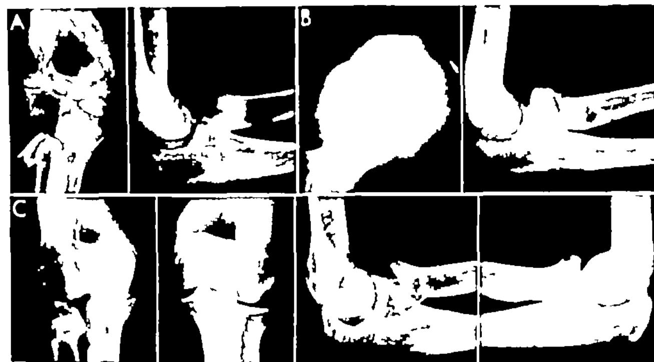


Fig 506 —A, anteroposterior and lateral views of fracture of radial head in a 12 year-old boy showing injury through epiphysial plate before reduction. B after reduction C 4 years after injury anteroposterior and lateral views of both injured and normal arm (injured arm on left) Some deformity of the radial head and slight shortening of the radial shaft can be seen Carrying angle is normal flexion 140 degrees fixed flexion 10 degrees pronation 45 degrees supination 85 degrees

Proximal Radial Epiphysis

The proximal radial epiphysis appears about the fifth to seventh year and ossifies by the thirteenth or fourteenth year It is rather discoid in appearance and lies entirely within the elbow joint Although it forms the head and neck of the radius the epiphysis itself contributes little to the length of the shaft

In the young child this epiphysis is rarely fractured The displacement is usually slight and may be corrected by closed manipulation However displacement may be accompanied by rotation sometimes as much as 90 degrees in which case open reduction is required to replace the articular surface (See Chapter 19 on Dislocations and Fractures of the Elbow)

Unlike the distal radial epiphysis the proximal epiphysis tends to fuse after attempts have been made to replace it. This fusion may be followed by loss of elbow motion. In other words the proximal radial epiphysis does not tend to realign itself with the shaft Prognosis is more favorable if the displacement is entirely lateral Full range of motion and function have been reported when the epiphysis is allowed to remain displaced (Fig 506)

Proximal Humeral Epiphysis

This epiphysis appears about 6 weeks after birth In the beginning it is flat or discoid in appearance but by the third year it becomes conical in shape Nearly

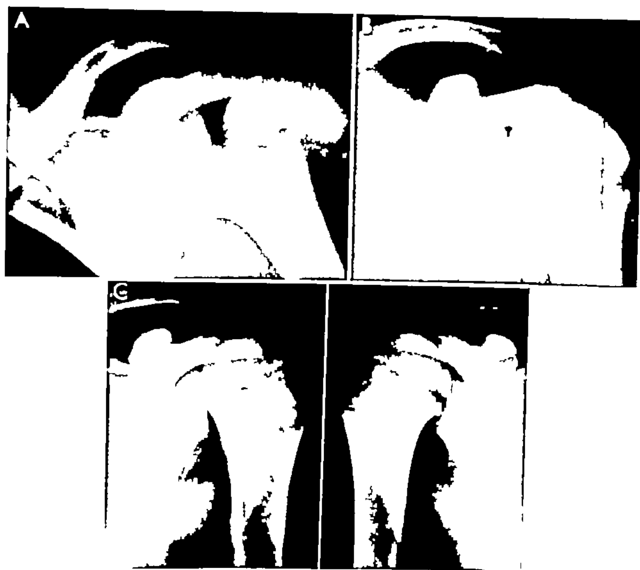


Fig 507 —A, anteroposterior view of left shoulder of 6-year-old boy who fell at play taken immediately after injury B postreduction on following day C 4 years later left and right proximal humeral epiphyses showing minimal growth disturbance due to injury

all of the length of the humerus comes from this growth area Ossification occurs at the nineteenth or twentieth year with the portion that is subjacent to t ater tuberosity ossifying last.

Fractures involving the i meral epiphysis may occur at rarely before the sixth year They occur most frequently between the eleventh and fifteenth years but they may even be found as late as the eighteenth year

Closed reduction may be difficult or impossible because of the inability of the surgeon to grasp the small movable epiphysis and to stabilize it during manipulation Splitting o lpping of the periosteum permits cement of the diaphysis and may ection difficult Also the tendon o ead of the biceps may be caugl the fragments

Since the humerus is usu

ally displaced laterally and upward reduction can ordinarily be obtained by applying traction with the arm in moderate abduction and forward flexion (Fig 508) If this procedure fails two other methods are recommended (*a*) traction on the arm positioned in adduction across the body and (*b*) suspension of the arm with traction in elevation at the head of the bed

Follow-up treatment is similar to the treatment of fractures of the surgical neck initial support to the arm in the resting position (arm to side) followed by a program of gradually increasing pendulum exercises

Distal Tibial Epiphysis

The distal tibial epiphysis appears at 5 months of age The internal malleolus appears at 8½ years as a downward projection of this epiphysis Rarely does the entire malleolus appear as a separate center of ossification When this does occur the condition may be erroneously diagnosed as a fracture of the entire malleolus Ossification is present at about the eighteenth year

Although most of the fractures in this region do not seriously damage the epiphysial cartilage (Fig 509) fractures do present a real hazard which requires that a careful watch be made for growth disturbance Since children have a tendency to "toe in" falls on the foot are apt to cause forced inversion Thus the astragalus is wrenched in the mortise and forced up against the internal malleolus causing a fracture which may injure the epiphysial cartilage sufficiently to cause growth disturbance Fractures through the epiphysial plate carry a poor prognosis

Reduction should be performed as gently and as accurately as possible If it is not perfect no more than two further attempts at reduction should be made because of the danger of damaging a portion of the epiphysis A long plaster-of paris casing should be worn for 6 weeks and no weight bearing permitted for 8 weeks

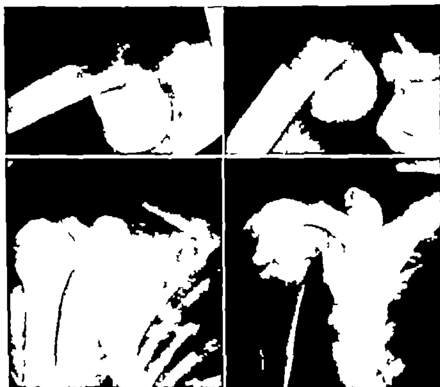


Fig. 508 —Top anteroposterior and oblique views showing proximal separation of right humeral epiphysis Bottom anteroposterior view immediately after reduction by closed manipulation and same view showing end result complete correction and normal growth.

Deformity is quite likely to occur despite splinting—depending of course on previous damage

Prognosis is guarded because ossification may occur in 1 year if the epiphysial cartilage has been crushed (Fig 509-1) This circumstance may lead to serious deformity which may eventually require osteotomy of the distal tibia and fibula. If the entire epiphysis is displaced without fracture through the epiphysial plate reduction of the epiphysial separation is usually followed by continued growth

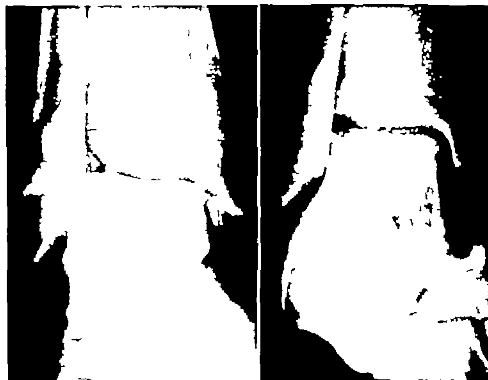


Fig 509 —*Left* anteroposterior view of distal end of right tibia in a 14-year-old girl, who fell and fractured lateral portion of distal tibial epiphysis. The fracture line did not pass through the epiphysial plate or into the diaphysis *Right* anteroposterior view 15 months after injury satisfactory healing with no deformity (Courtesy of the Hospital for Sick Children Toronto)

Proximal Tibial Epiphysis

The upper tibial epiphysis is the second largest epiphysis in the human body It is present at birth and unites with the diaphysis in the twentieth to the twenty second year Although this epiphysis is flat and regular in shape it possesses a tongue like projection in front which in the beginning is cartilaginous and later forms the bony tubercle The greater portion of the length of the tibia occurs from the upper tibial epiphysis

Although fractures of this epiphysis are rare torsion injuries occur occasionally and may produce premature ossification. There are also the so-called "bumper" fractures (Fig 510) which result from forces received on the lateral aspect of the upper leg or knee When the knee is thus forced into a valgus position the lateral femoral condyle crushes the lateral condyle of the tibia Such injuries may produce growth disturbances in the growing child (Fig. 511)

The torsion type of fracture may usually be treated by manipulation and plaster fixation for 6–8 weeks Because the proximal tibial epiphysis is so large considerable force is required to displace it thus premature ossification may result In the bumper type of crushing injuries ossification may appear at the site of fracture while the other portion of the epiphysis





Fig 509 1 —Showing the effect of severe epiphysial injury the result of an open comminuted fracture of distal tibia and fibula, right in 9 year old boy A, lateral and anteroposterior views taken shortly after original injury B lateral and anteroposterior views of both legs 2 years after injury revealing growth disturbance of distal tibial epiphysis C lateral and anteroposterior views 3 months after corrective osteotomy of both tibia and fibula with wedge of bone removed from upper tibia and placed in osteotomy site of tibia posteriorly and mesially

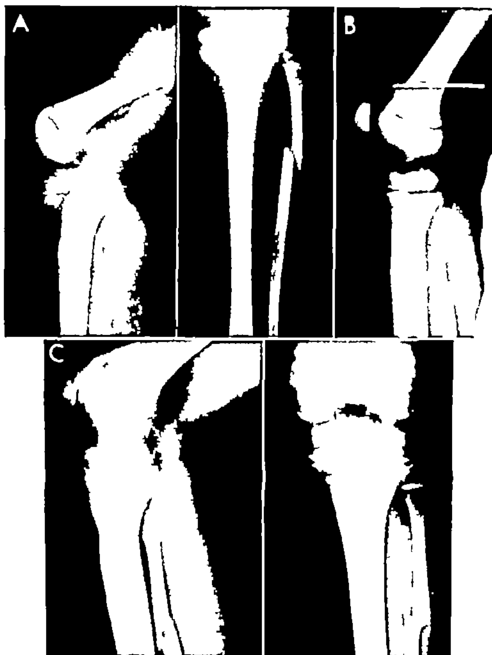


Fig 510 —A, lateral and anteroposterior views of fracture of the tibia through the epiphysis in a 9-year-old boy who was hit by an auto B Kirschner wire inserted in right femur Treatment then consisted of closed reduction of separated proximal tibial epiphysis followed by application of plaster spica. Tibial epiphysis reduced to satisfactory position. C 3 months after injury indicating satisfactory healing. It is too early to determine whether there has been an arrest of any portion of the growing epiphysis

may continue to grow resulting in a marked knock knee Stapling the uninjured portion of the epiphysis may prevent marked deformity but if the injury is neglected or if the stapling is not entirely satisfactory osteotomy for correction may be necessary

Distal Femoral Epiphysis

The distal femoral epiphysis is the largest of all the epiphyses in the human body and has the most active growth Most of the growth of the femur takes place from this epiphysis The ossification center is present at birth and complete union with the metaphysis is usually present by the nineteenth year This epiphysis is slightly convex in both the anteroposterior and the lateral views It includes the whole of the articular surface of the lower end of the femur and from it most of the muscle fibers of the gastrocnemius take their origin

Because of the large surface of this epiphysis severe trauma is necessary to produce separation. Separation may occur early or late in the growth period (Fig 512) While not common today in the days of the horse and carriage boys hanging on the backs of moving wagons at times caught their feet in the spokes of the wheels and the severe twisting motion caused separation of the distal femoral epiphysis When separation occurs the force may cause some compression of the growing cartilage cells resulting in premature ossification and growth disturbance Fortunately separation can occur without severe injury to the growing cells (Fig 513)

Injury to the popliteal vessels may be caused by pressure from the distal end of the shaft of the femur or from the epiphysis when it is displaced posteriorly

In treating open fractures in this region, great care must be exerted to spare the cartilaginous plate from further damage Examination soon after injury may reveal the deformity and the diagnosis may be made by palpation After swelling has appeared however roentgenograms are imperative in order to make the diagnosis Treatment is dictated by the position of the fragments Traction is applied



Fig 511 —Marked genu varum in a 9-year old boy the result of a knee injury 3 years previously Osteotomy of the upper tibia and fibula will be required to correct the deformity (Courtesy of the Hospital for Sick Children Toronto)

to the leg with the knee in flexion and countertraction to the thigh The displaced epiphysis is repositioned to the femoral shaft. Plaster is applied from toes to groin with the knee in sufficient flexion to relax the gastrocnemius muscle and maintain reduction However careful inspection of the foot for color sensation and toe motion must be made Evidence of severe vascular damage will require removal of the plaster and possibly surgical exploration of the popliteal space



Fig 512.—A, separation of distal femoral epiphysis in 18-month-old child B 1 month after reduction and plaster fixation A new deposit of calcium can be seen forming a new shaft of the femur leading to the epiphysis as though a periosteal sleeve had extended from the shaft to the epiphysis C 2 weeks later The new shaft is better defined and the old shaft is taking on the appearance of a sequestrum. D 3 months after injury The new shaft is fairly well defined the old shows signs of erosion E 6 months after injury The new shaft is now well defined and the old is rapidly disappearing.

PROXIMAL FEMORAL EPIPHYSIS

Marked displacement of the capital femoral epiphysis may occur after sudden severe trauma in an apparently normal child But a somewhat similar displacement may occur over a period of time i e the condition commonly known as "slipped capital femoral epiphysis" may appear suddenly

This epiphysis is particularly prone to injury because of the unusual shearing forces present in this area Frequently susceptibility to shearing occurs in the overweight rapidly growing child with the so-called Frölich syndrome However it may also occur in the tall thin child with an excess of growth hormones Harris demonstrated that he could alter the shearing

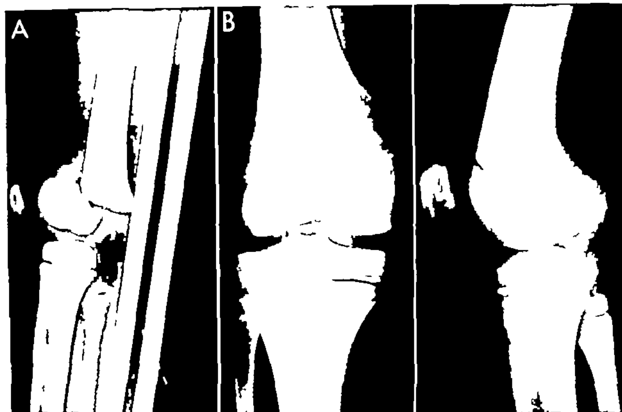


Fig 513 —A, lateral view of distal femoral epiphysis with anterior separation in a boy aged 7 who was struck by an automobile Treatment consisted of traction to disengage the fragments flexion of the knee gentle pressure over the epiphysis anteriorly and counterpressure under the distal end of the shaft posteriorly under general anesthesia B anteroposterior and lateral views 5 years later no deformity (Courtesy of Tom Outland M.D)

or slowly Prognosis varies accordingly In the case of the sudden complete slip resulting from a severe trauma the injury to the growing portion of the epiphysis may be so severe that aseptic necrosis and growth deformity are almost inevitable On the other hand in a rapidly growing adolescent with or without severe trauma to the hip region, displacement of the epiphysis may occur slowly Unless careful attention is paid to limp and pain referred to the knee a so-called "minimal" slip of the capital femoral epiphysis may be missed

strength of the epiphysial plate in growing rats by administering hormones He found that the female sex hormone increased and the anterior pituitary growth hormone decreased the shearing strength by altering the thickness of the "layer of hypertrophied cartilage cells immediately on the epiphysial side of the layer of provisional calcification " The more rapid the growth the less trauma required to produce the slip Lack of pituitary hormones has been demonstrated to affect slipping of this epiphysis in adults up to 26 years of age

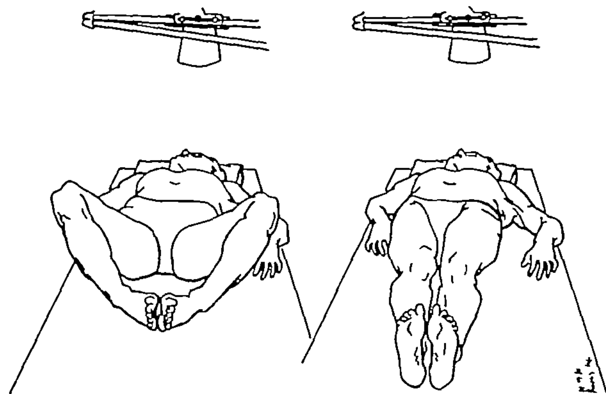


Fig 514 —Positioning for bilateral hip roentgenography lateral at left anteroposterior at right Both hips are included on a 14 × 17 inch film placed transversely The tube is centered above the midpoint of a line connecting the acetabula (From Joplin R. J Slipped capital femoral epiphysis Am. Acad. Orthop Surgeons Lect Vol VII 1950 and from Klein A. Joplin R. J Reidy J A. and Hanelin J Roentgenographic features of slipped capital femoral epiphysis Am J Roentgenol 66 361 1951)

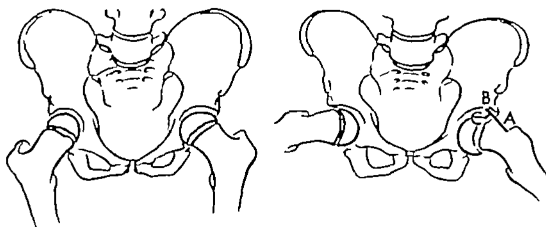


Fig 515 —Showing minimal slipping upper femoral epiphysis The displacement is not apparent in the anteroposterior view (left) but is noticeable in the lateral view (right) Line *AB* indicates the superior border of the femoral neck projected *BC* the distance from the femoral head to the projection of the superior border of the femoral neck—the distance that the head has slipped

Recently Ponseti studied biopsy specimens from the femoral neck and head in patients with early slipping of the upper femoral epiphysis The wide epiphysial plate lesion in these specimens appeared to be due to the "loss of cohesion of the cartilage matrix presumably caused by an alteration of the chemical composition of the ground substance" Ponseti concluded that this lesion appeared to be mainly responsible for the epiphysial slipping He further demonstrated an abnormality in the protein metabolism similar to that found in children with adolescent scoliosis The epiphysial plate lesions in these patients were similar to the lesions observed in experimental animals fed minimal amounts of ammonionitrates.

Thus it would appear that slipped capital femoral epiphysis may be caused by severe trauma in normal children or by minimal or moderate trauma in children with altered metabolism or endocrine disturbances

In making a diagnosis of slipped capital femoral epiphysis various factors should be considered, since the injury may occur either in a child or under rare circumstances in an adult (pan pituitary disease) The diagnosis may be suspected in an adolescent child (6–18 years) who limps or complains of pain in the region of the hip anterior thigh or knee Examination usually reveals that the hip is held in external rotation Flexion of the hip may cause further external rotation If the slipping is marked the patient may walk with an antalgic gait leaning toward the affected side to avoid painful weight bearing

Roentgenograms (Fig 514) reveal the characteristic findings The lateral displacement may be determined satisfactorily by taking views of both hips on one film with the soles of the patient s feet touching each other and with the knees flexed and drawn apart as much as is comfortably tolerated The anteroposterior view is obtained in a similar manner by keeping the medial sides of the feet touching and the knees extended completely Even minor slips in either the posterior type or the mesial type or a combination of these two may be determined by comparing the x ray films with a set of roentgenograms of a normal hip taken in comparable positions of a child (or rarely an adult) same age and sex.

Once the diagnosis of slipped capital femoral epiphysis has been made on one side the child must be watched for a further slip on the opposite side since bilateral slipping occurs in about 40 per cent of the cases

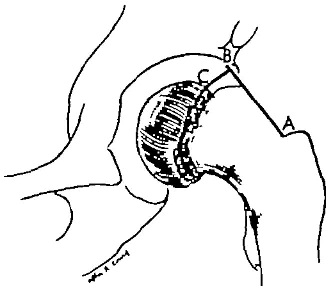


Fig 516—Diagram of close-up view of abnormal hip lateral view This is a magnification of the right-hand view in Figure 515

The type of treatment depends on the degree of slipping measured in either the anteroposterior or lateral view (Figs 515 and 516) If the slipping is less than 1 cm manipulation is not necessary A 3-flanged nail is introduced from the lateral aspect of the femur about 1¼ inches below the tip of the greater trochanter If the child is small, the ordinary Smith Petersen nail should be noncannulated, smaller than the standard adult size and the edges of its flanges extremely sharp in order to penetrate the hard epiphysial plate To avoid displacing the epiphysis still farther the head and neck should be transfixed with a Kirschner wire inserted prior to nailing In general, 3 types of displacement



Fig 517 —Minimal posterior slip of capital femoral epiphysis in boy aged 12 The antero posterior view (A) shows the widened irregular epiphysial line only (right hip) but the lateral view (B) shows a definite slipping C and D after nailing in situ of right hip with Smith-Petersen nail E showing growth of head of right femur away from the nail which was centrally placed and did not arrest the epiphysis F and G showing further growth of head away from the nail The epiphysial line appears essentially normal on both right and left at this time 20 months after nailing Patient is clinically symptom free

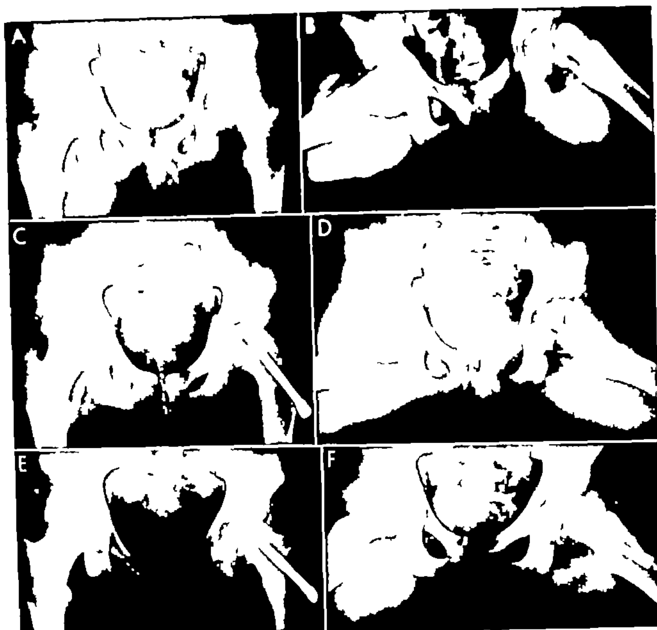


Fig 518 —Marked slipped epiphysis in 14½ year-old boy A, anteroposterior view showing moderate inferior displacement (left hip) B lateral view showing marked posterior displacement with fragmentation and widening of epiphysial line C and D showing good reduction with centrally placed Smith-Petersen nail crossing the epiphysial line E and F 2 years postoperatively showing closure of epiphysis with no evidence of aseptic necrosis The nail has not changed position

may occur in the upper femoral epiphysis a minimal slip a marked slip without aseptic necrosis and a marked slip with subsequent development of aseptic necrosis

Minimal Slip of Capital Femoral Epiphysis —A 12 year-old boy fell while playing on a swing 2½ months prior to admission to the hospital, and sustained an injury in the region of his right hip Since that time he noticed a limp and felt some pain in the anteromedial aspect of his right thigh with slight external rotation of his right leg He also noticed a tendency for his right toe to point inward Because the pain gradually increased he was admitted to the hospital where roentgenograms (Fig 517 *A* and *B*) revealed a widened, irregular epiphysial line with slight posterior slipping of the right femoral head

Treatment consisted of nailing in situ which was done the day after admission Convalescence was uneventful. The boy was permitted to walk with crutches after 1 week.

Roentgenograms taken 2 months after operation (Fig 517 *C* and *D*) revealed no change in the epiphysis Films made 8 months later (Fig. 517 *E*) revealed no further slipping of the epiphysis the nail showed no change in its position and the head and neck of the right femur appeared to be growing normally The patient was symptom free going to school and living a normal life

Roentgenograms 20 months after nailing (Fig. 517 *F* and *G*) revealed that, although the nail remained unchanged, the *head of the femur had grown away from* the nail. The boy who was symptom free was advised to return to the hospital during his summer vacation to have the nail removed. (He would be 14 years of age at that time)

Comment —Such a recommendation is made routinely to prevent a fracture below the greater trochanter where the nail pierces the outer femoral cortex. Several fractures have been reported in the area following participation in the so-called "contact sports" such as football when the *nail has been left in the femur*

When the slip is of more than 1 cm as demonstrated by the roentgenogram in either the anteroposterior or lateral view open reduction, accurate replacement of the head onto the neck, and insertion of a 3-flanged nail is advised. Various operative techniques have been devised to accomplish this difficult procedure

Marked Slipped Epiphysis Treated by Open Reduction and Nailing with No Aseptic Necrosis —*Anteroposterior and lateral views of the pelvis of a 14½ year-old boy who 10 months before* developed a painful limp of the right leg due to Osgood-Schlatter disease Two months later (4 months before admission) a limp developed on the left side with pain in the left thigh The boy walked with a swaying left leg limp carrying his left knee in a slight valgus deformity and with some inward rotation X ray films revealed typical findings of moderate medial and marked posterior slipping of the left capital femoral epiphysis (Fig 518 *A* and *B*) The comparative range of motion of the two hips was as shown in Table 21

Open operation was carried out through the Gibson incision Walking on crutches was started in 3 weeks Roentgenograms 2 months later (Fig 518 C and *D*) revealed

TABLE 21 —Range of Motion of Hips before Operation for Marked Slipped Epiphysis

	Left Hip	Right Hip
Flexion	110	135
Extension	0	20
Abduction	30	60
Adduction	30	20
With both hips flexed 90		
External rotation	45	60
Internal rotation	–10	30
With both hips extended:		
External rotation	30	60
Internal rotation	0	45

a good reduction with the nail across the epiphysial plate in both anteroposterior and lateral views

Three months later crutches were omitted Examination revealed a normal gait

Roentgenograms 2 *years postoperation* (Fig 518 *E* and *F*) *showed no appreciable* change in position of the femoral head or Smith Petersen nail Since the epiphysial line appeared closed the nail was removed

Three years after operation the patient wore a ½ inch lift on his left heel. His reactions to the Trendelenburg test were negative He played baseball and basket ball. Table 22 shows his hip motions as of that time

Comment —Thorough follow up studies of all cases of slipped upper femoral epiphyses *treated for many years at the Massa*chusetts General Hospital have demonstrated the advantage of early diagnosis and prompt treatment.

Growth of the epiphysis may not be arrested by a 3-flanged nail driven across the epiphysial plate through the neck into the head provided that the nail is kept within

the central portion of the neck and head

Cases treated by nailing in situ may be allowed out of bed after 10 or 12 days and walking started with the aid of crutches with partial weight bearing being permitted from the beginning As soon as the patient can bear full weight on the affected side without discomfort the crutches may be discarded

TABLE 22.—RANGE OF MOTION OF HIPS 3 YEARS AFTER OPERATION FOR MARKED SLIPPED EPIPHYSIS

	LEFT HIP	RIGHT HIP
Permanent flexion	0	0
Flexion	135	135
Extension	10	10
Abduction	40	40
Adduction	30	30
With both hips flexed 90 :		
Internal rotation	40	40
External rotation	40	40
With both hips extended		
Internal rotation	40	45
External rotation	25	60
Leg length (anterosuperior spine to internal malleolus)	36¾ in	37¼ in.

In those cases treated by open reduction bed rest is maintained with the leg in balanced suspension traction for 2–3 weeks and partial weight bearing permitted with crutches which may be discarded in 2 months. These patients must be followed by roentgenograms taken every 3 months until the epiphyses are completely closed after which the nail may be removed

Complications in the form of aseptic necrosis of the head of the femur appear occasionally despite all treatment.

MARKED SLIPPED EPIPHYSIS TREATED BY OPEN REDUCTION AND NAILING WITH ASEPTIC NECROSIS AND RESULTANT PERMANENT STIGMATA.—About 8 months before admission but without any history of injury the patient noticed discomfort on arising from the sitting position After walking a few steps his pain seemed to disappear He did not seek medical advice until, on the day of admission he fell while running down a hill At this time he struck his right knee on a sharp stone and had such severe pain in the right hip that he was unable to arise alone Roentgenograms (Fig 519 *A* and *B*) revealed bilateral slipped capital femoral epiphysis He weighed 185 pounds at the time His right leg was placed in traction for 5 weeks Four months later open reduction and nailing of the left upper femoral epiphysis were carried out The same procedure was done on the right hip 1 month later (Fig 519 *C* and *D*) Although his postoperative course was uneventful, 5 months later (Fig 519 *E* and *F*) roentgenograms revealed some aseptic necrosis on the right Sixteen months later he weighed 201 pounds he was still walking with crutches and his right leg was short. His hip motions at that time were as shown in Table 23

TABLE 23 —RANGE OF MOTION OF HIPS 16 MONTHS AFTER OPERATION FOR MARKED SLIPPED EPIPHYSIS WITH ASEPTIC NECROSIS

	RIGHT HIP	LEFT HIP
Permanent flexion	30	10
Further flexion was possible to—	85	110
Abduction		20
Permanent adduction	10	
Further adduction	Jog	25
Permanent external rotation	10	
Further external rotation	Jog	5
Internal rotation		60

Seven years after his operations (Fig 519 *G* and *H*) the patient was still overweight. His reactions to the Trendelenburg test were negative He was able to walk on tip toes and do a deep knee bend Hip motions as of that time are given in *Table* 24

TABLE 24 —RANGE OF MOTION OF HIPS 7 YEARS AFTER OPERATION FOR MARKED SLIPPED EPIPHYSIS WITH ASEPTIC NECROSIS

	RIGHT HIP	LEFT HIP
Permanent flexion	10	10
Further flexion	90	100
Both hips flexed 90		
Permanent external rotation	20 –Jog	
Permanent internal rotation		10 –45
Abduction	10	15
Adduction	15	20

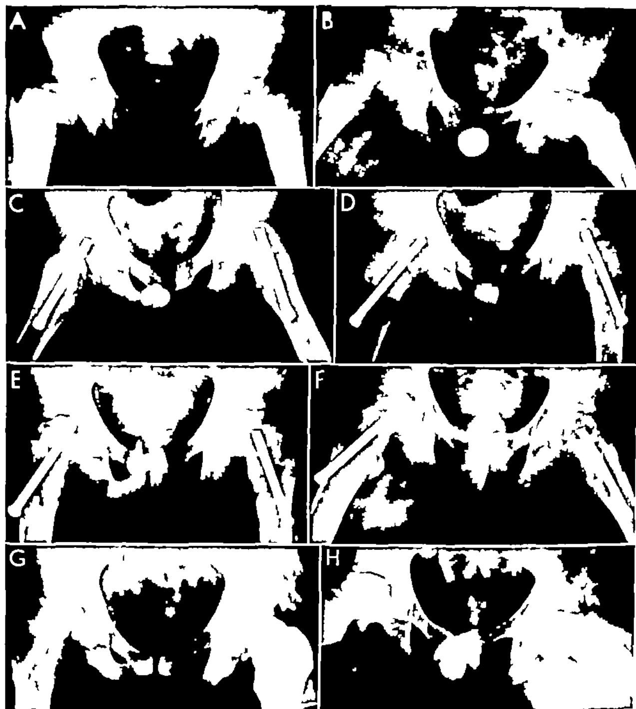


Fig 519 —Marked slipped epiphysis in an adult. A and B on admission to hospital severe slipping of head on right, both downward and backward more marked on lateral view C and D shortly after open reduction and nailing bilaterally E and F 5 months after operation; some aseptic necrosis evident on the right. G and H 7 years after operation moderate hypertrophic changes on the right, with narrowing of the joint space but only minimal changes on the left.

The right leg was about 1 inch shorter than the left.

Eight years after operations the patient was free from pain except after engaging in heavy lifting for 15–20 minutes He could stand for 8 hours and could walk without pain but he did show a mild limp on the right His reactions to the Trendelenburg test were negative bilaterally He was unable to put on his right shoe alone

Although his left hip was rated a good result the right hip was rated only fair Furthermore it was thought that surgery might be needed on the right hip some time in the future since increased pain was considered likely

Comment.—The aseptic necrosis and resulting deformity here may have been due to the marked changes present in the neck of the femur prior to surgery

Metatarsal and Metacarpal Epiphyses

The epiphyses of the metatarsals and metacarpals are located distal to the shafts of the bones except in the great toe and the thumb where the epiphysis is proximal to the shaft. An attempt should be made to reduce the displaced epiphysis if growth disturbance is to be avoided The shaft has a tendency to grow toward the displaced epiphysis Where displacement is only slight the disturbed relationship may result in only minimal or no discomfort.

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32 

Operative Treatment of Fractures

THE ULTIMATE OBJECTIVE of any physician who is treating a fracture is to promote healing of bone with normal alignment and length to restore joint function of the extremity and to return the individual to his usual economic status in the shortest possible time With these ideas uppermost in his mind the surgeon has in many instances resorted to operative treatment of fractures

Such has been the trend particularly in America since World War I and more particularly since noncorrosive metals became available about 1940 When the over-all results of the operative treatment of fractures are considered, it is most difficult to determine whether the advantages of operative treatment outweigh the disasters that sometimes follow the open treatment of long-bone fractures One case of osteomyelitis following an elective operation on a closed fracture will not soon be forgotten by the operating surgeon The surgeon must recurrently ask himself "Will the fracture heal in a reasonable time with nonoperative methods?" Or "Do I have the experience and training the tools and the surroundings to insure a better result in a shorter period of time by operating on the fracture at hand?"

The success or failure of the operation will depend largely on the surgeon Therefore the mind of the student must be inculcated with the importance of proper training in fundamental surgical principles of postgraduate study and of careful judgment in the selection of cases for operation for improper operative interference is one of the most common causes of delayed union or nonunion of bone.

K. W Starr wisely states "If the dread of bone infection following operation on fractures remains like the sword of Damocles over our therapeutic head during the next decade surgical training not the pathology of bone is at fault"

The vast majority of long bone fractures will heal if realigned and held sufficiently long with uninterrupted external fixation. It is recognized however that some fractures are best treated by operative means either because of necessity or because this means is the choice of the surgeon.

The operative management of fractures received its greatest stimulus from the work of Sir Arbuthnot Lane at Guys Hospital in London in the latter part of the nineteenth century In 1912 Sherman, of Pittsburgh also advocated early operative reduction of long bone fractures The metals used by these two surgeons caused tissue reactions and frequently had to be

removed (Sherman later abandoned his "vanadium steel" in favor of 18–8 S Mo stainless steel) Venable and Stuck in their excellent monograph on *The Internal Fixation of Fractures* point out that in 1922 C M Johnson of Pittsburgh secured patents for a chrome nickel stainless steel which contained 10–20 per cent chromium and 9–25 per cent nickel and was characterized by the presence of about 2 per cent silicon that later studies caused the proportions to be altered to 18 per cent chromium and 8 per cent nickel with a substantial proportion of silicon and that this latter proportion is used basically in all the present-day "18-8 stainless steels" In 1946 Key observed the deleterious effects of electrolytic reaction in the body fluids and between the different types of stainless steels Moreover he found that the stainless steels vary enormously in their resistance to corrosion and that mixing of stainless steels in the same patient produces destruction of bone By present standards 18-8 S.Mo stainless steel (Table 25) is the only steel which can be used in the body without danger Even so there is still some slight disintegration of the metal, which can be demonstrated by analyzing tissue around the metal but the corrosion of the metal is minimal and the interference with healing of the soft tissues is reduced considerably While reaction in the tissue occurs rarely after using 18-8

TABLE 25 —SPECIFICATIONS OF STAINLESS STEEL 18-8 S.Mo

Chromium	17–20%
Nickel	10–14%
Molybdenum	2–4%
Manganese	2% maximum
Carbon	0 08% maximum
Silicon	0 75% maximum
Phosphorus	0 03% maximum
Sulfur	0 03% maximum
Iron	Remainder
Rockwell hardness	30 –35 C

S Mo stainless steel, breakage is by no means uncommon. We do not as yet, have the ideal stainless steel for internal fixation of fractures

In 1929 Venable and Stuck advocated the use of Vitallium an alloy of cobalt chromium and molybdenum with small amounts of manganese silicon and carbon Vitallium is extensively used in the manufacture of plates screws nails molds

TABLE 26 —SPECIFICATIONS OF VITALLIUM

Cobalt	65%
Chromium	30%
Molybdenum	3%
Manganese, Silicon, Carbon	Remainder

for arthroplasty prostheses etc It is a very hard alloy which is less malleable than most alloys and hence cannot be machined Therefore appliances made of Vitallium must be cast in molds Vitallium as now manufactured (Table 26) can be bent to conform to the part if necessary

TRAINING OF THE FRACTURE SURGEON

Along with improvement in available metals has come more effective training of the fracture surgeon. He must first be experienced as a general surgeon and second be trained to deal with the nonoperative and operative management of bone and joint injuries He should be able to determine which cases require operation

SELECTION OF CASES FOR OPERATION

Certain fractures should be treated primarily by operation These are

1 Fractures of the olecranon with separation of the fragments

2. Fractures of the radial head or neck with gross displacement in adults

3 Fractures of the lateral condyle of the humerus with marked rotation in children or in adults

4 Displaced fractures of the femoral neck

5 Certain fractures of the intertrochanteric region when bone is not too osteoporotic or too comminuted

6 Patellar fractures with separation of

the fragments and laceration of the quadriceps expansion

Another group of fractures which may justifiably be treated by open reduction includes

1 Posterior dislocation of the humeral head with fracture

2. The Monteggia fracture

3 Certain fractures of both bones of the forearm in adults

4 Carpal dislocations or fracture dislocations in which manipulation has failed

5 Fracture of the posterior and superior acetabular rim with marked displacement with or without sciatic nerve injury

6 Fractures of the femoral condyles with severe rotation

7 Oblique fractures of both tibia and fibula at the junction of the middle and lower thirds with torsion or shortening

8 Joint fractures particularly those of weight bearing joints in which there is gross misalignment of the articular surfaces

9 Shaft fractures near a joint, particularly in the lower extremity where traction or manipulation will not realign the fragments so as to prevent ultimate deformity of the joint

10 Fractures with gross interposition of soft tissue

11 Fractures with a large interposed third fragment holding the main fragments apart

12. Fractures with marked shortening which cannot be corrected by traction or manipulation

A third group of fractures in which open reduction and internal fixation are usually *contraindicated* includes

1 Essentially all fractures in children under 12 years except fractures of the lateral humeral condyle

2 Impacted fractures of the surgical neck of the humerus

3 Most fractures of the humeral shaft

4 Most fractures of the supracondylar region of the humerus

5 Colles fractures

6 Impacted fractures of the femoral neck in valgus

7 Moderately displaced or grossly comminuted fractures of the tibial table.

8 Most fractures of the tarsal bones unless there is associated irreducible dislocation.

PREPARATION OF THE PATIENT

Once operation is decided on certain fundamental rules must be followed in the preparation of the patient. The usual principles applicable in any major operation must be observed The more quickly the operation is carried out, the easier it will be on the patient and the more rapidly will pain be relieved and the healing process of the fracture begun. Stabilization of the fracture will help materially to reduce the shock that accompanies injury The only reason for delay is an unfavorable condition of the local tissue or of the patient. While the surgeon cannot plan every detail of his operation beforehand he should have in mind a general scheme as to his method of reduction and fixation of the fracture He should look over his instruments before the operation and be certain that the necessary tools are on the "sterile table" Nothing is more frustrating than not to have the proper size drill, screws, plates etc at hand the moment they are needed

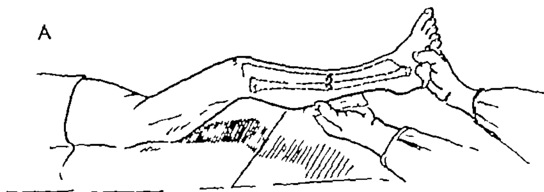
For local management (Fig. 520) the following should be observed

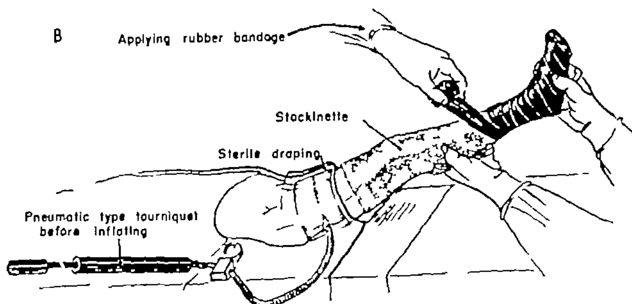
1 One careful preparation of the extremity is sufficient

2 It is probably better to do the local preparation in the operating room under anesthesia This requires (*a*) Sufficient help in handling the injured extremity to prevent additional trauma (*b*) cutting of toenails and fingernails (*c*) careful shaving (*d*) gentle scrubbing with gauze immersed in liquid soap and water (*e*) the application of an antiseptic solution of the surgeon's choice

3 The extremity should be carefully draped

4 The use of a tourniquet is optional





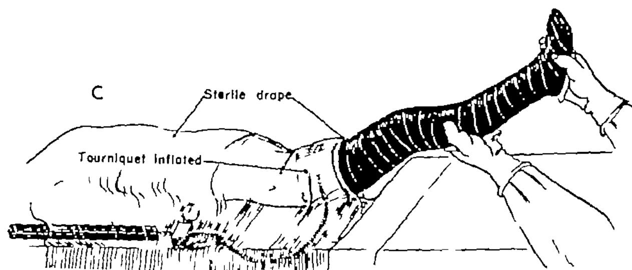
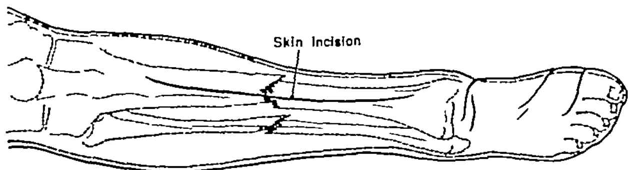
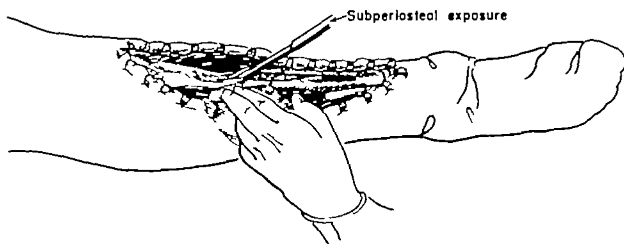
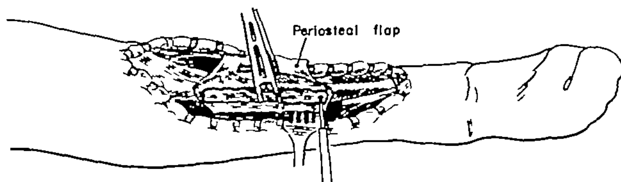


Fig. 520 —Preparation of patient for surgery for fracture The extremity must be adequately supported and if a tourniquet is used it should be of the pneumatic type A, preparation of skin B and C draping of extremity and application of tourniquet Before the tourniquet is inflated a rubber Esmarch bandage should be used to deplete the extremity of blood The tourniquet is then inflated and the Esmarch bandage removed







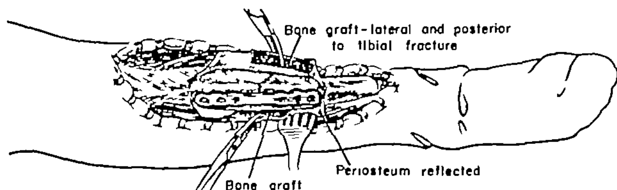


Fig 521 —Operative approach and fixation of a long bone fracture

If the tourniquet is used the pneumatic type should be applied before the extremity is prepared After the usual draping and before inflation of the tourniquet a rubber Esmarch bandage should be applied from below upward over stockinette covering the extremity After the bandage is applied the tourniquet should be inflated to the degree indicated on the dial of the tourniquet. The bandage is then removed

tion of the fragments with bone clamps All major fragments are brought into line and fitted as accurately as possible to their normal position When this is done the surgeon decides what type of internal fixation to use He has a choice of screws a plate and screws bands circular wires or medullary nails Rarely will suture material such as silk or catgut give stability to any fracture

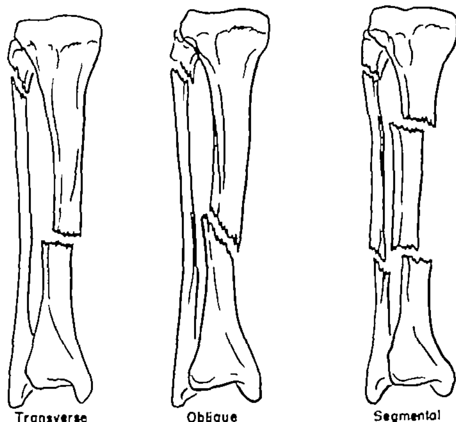


Fig. 522.—Types of long bone fractures Any of the three types may be comminuted.

OPERATIVE TECHNIQUES

The operative approach and fixation of a long-bone fracture are diagramed in Figure 521 The skin incision must be adequate to allow subperiosteal exposure of the fragments without undue tension on the skin edges Superficial sensory nerves must be avoided. Metal clips secure the stockinette to the skin Where possible the incision should follow muscle planes down to bone The periosteum and muscles are carefully and sufficiently reflected in one layer from the ends of the broken bones to allow gentle manipulation and reduc

In general there are three types of long bone fractures (Fig 522) (1) transverse (2) oblique and (3) segmental Any of the three may be comminuted And in general the methods of internal fixation (Fig 523) vary as follows (1) plate and screws for the transverse or short oblique fracture (2) screws only for the long oblique fracture (3) a medullary nail for the segmental fracture A combination of a plate and/or screws may be used for the comminuted fracture Intramedullary fixation has largely replaced screws and plates for femoral fractures

Technique of Applying Plates and Screws

The technique of fixation of bone by plates and screws used by L T Peterson (Fig 524) is an excellent one The plate should conform to the shape of the bone and any inequality should be adjusted by accurate shaping of the plate before it is fixed It is not good technique for the drill vertically to the plate as well as in the center of the hole A drill guide will aid in determining this direction The drill point should be turned without describing an arc which tends to enlarge the hole A motor-driven drill possesses certain advantages over the hand drill because it is mechanically powered and the operator can devote his attention to direction If the drill is thrust through the bone at high

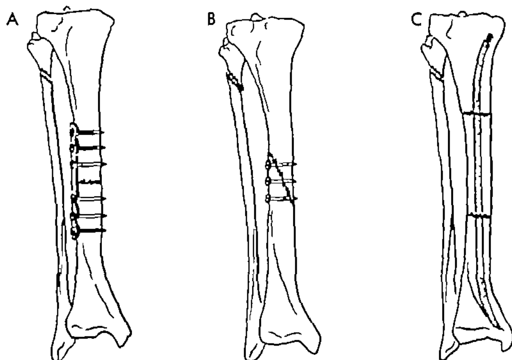


Fig 523 —Types of long bone fractures with appropriate internal fixation A, plate and screw fixation for transverse comminuted closed or open fractures B screw fixation for spiral oblique fracture C medullary nail for segmental fracture

screws to bend the plate to fit the bone since in so doing a spring action results and the screw is immediately subjected to a strong pulling-out force The screw should fit in the center of the hole in the plate so that the head of the screw will have uniform contact and pressure on the plate If the screw is not properly centered as it is tightened the countersink in the plate will tend to force it to one side thereby damaging the good threads already cut in the bone and producing a strain which will probably lead to necrosis and early loosening of the plate

In order to have uniform contact between plate and screws it is important to speed it will burn the bone and produce necrosis A slow rate of speed is therefore desired this not only avoids unnecessary bone damage but it is safer for the patient and the operator The drill must be sharp and of proper size and it should be just slightly smaller than the screw which is to be used The screw should pass through both cortices of bone The screw with a pilot point is desirable in that the point of the screw will "find" the hole in the opposite cortex The point of the screw should project through the length of the pilot point Sometimes it is necessary to insert screws at an angle in order to engage some of the bone fragments It is best

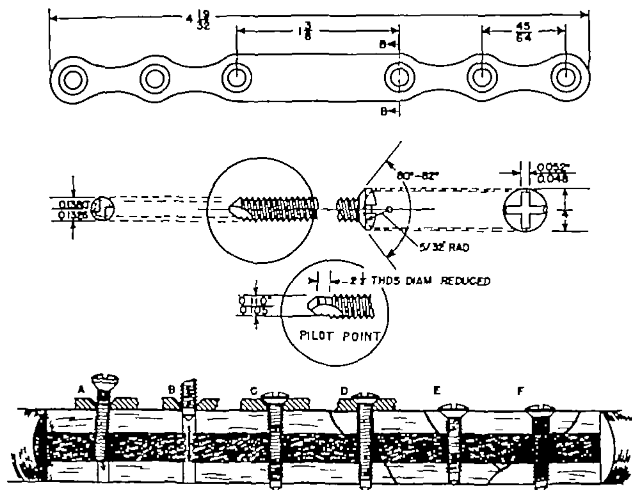


Fig 524 —Details of construction of plates and screws (18-8 S.Mo stainless steel) Inset shows the cruciate head the cutting flutes and the pilot point of the screw The lower drawing shows the technique in plate and screw fixation

A, a long screw without pilot point inserted at slight angle in relation to the drill hole This procedure is common in actual practice The point may completely miss the hole or it may hit the hole eccentrically Then, as the point is forced into line it will tend to strip the threads already cut in the proximal cortex.

B a screw with a pilot point The tip accurately fits the drill hole and tends to direct the screw properly Furthermore the pilot point holds the screw so that the screw may be more easily controlled without the use of a screw-holding device on the screw driver A longer pilot point would be more effective for both purposes but this portion of the screw does not engage the bone

C a long pilot-point screw properly centered and of optimum length.

D enlarging the hole in the proximal cortex. After both cortices have been drilled with a No 35 drill, the hole in the proximal cortex is enlarged by a No 27 drill (0 144 inch) so that the threads engage only the distal cortex The whole screw acts as a pilot point. This method makes possible the impaction of fragments when the screw is tightened

E, two fragments of bone fixed with a screw without use of a plate The hole in the proximal cortex has been countersunk. This avoids the tendency for the tapered head to split the bone It also makes the head less prominent.

F the proximal hole enlarged as in D and countersunk as in E, permitting impaction of the fragments Methods E and F are applicable in fixation of fragments and of onlay bone grafts

(From Peterson L. T : Fixation of bones by plates and screws J Bone & Joint Surg 29 335 1947)

to use a separate screw for this purpose since angular screws give poor contact with the plate In fixing a bone graft a flat headed screw may be desirable because a tapered screw head tends to split the bone This hazard can be eliminated however by the use of a countersink which will serve to make the screw head less prominent. The countersink is also useful where fragments are secured by screws without the use of plates

THE SLOTTED PLATE —The use of various mechanical devices for stabilizing fractures often provokes controversy Perhaps no means of internal fixation of long bones has been more controversial than the slotted plate The plate is designed to prevent rotation at the fracture site but at the same time to allow impaction of the bone fragments as muscle contraction occurs (Fig 525) There are several types of slotted plates—e g the Eggers plate and the Townsend-Gilfillan plate

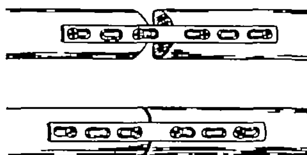


Fig 525 —Application of a slotted plate Top screws placed as far from fracture line as possible to allow impaction Bottom impaction occurs as plate moves on screws owing to muscle contraction

The technique of introducing the slotted plate is the same as that for any other type of bone plate except that screws may be placed at any point in the slot other than at the end of the slot nearest the fracture line When the screws are inserted and tightened against the plate they are then turned counterclockwise for 360 degrees Theoretically this loosening of the screws allows motion of the distal fragment of bone on the plate as normal muscle contraction occurs and impaction is permitted Whether actual impaction of the fracture occurs is a debatable point Some authorities (see Chapter 28 on Fractures of the Tibia and Fibula) believe that it does others think that it does not. However if the slotted plate is properly applied, it will be as effective as the standard plate. But whether it has any real advantage has still not been proved

The Addition of Bone

The addition of bone at the time of open reduction and internal fixation is frequently indicated (Fig 521) Many surgeons *prefer to add bone particularly if* delay in open reduction has been necessary The bone can be an osteoperiosteal graft from the surface of one fragment, or it may be taken from the ilium or bone bank. It should be placed subperiosteally preferably where muscle will cover the graft

Closure of the Wound

If a tourniquet is used it is released before the wound is closed An attempt is made to repair the periosteum with fine suture material Subcutaneous tissues are carefully repaired and the skin is closed without tension—by relaxing incisions if necessary

Usually some form of external fixation or traction is necessary after open reduction and internal fixation Plaster of paris is still the most reliable material in the hands of the average surgeon When used, it should include the joints above and below the region of fracture

Postoperative Elevation

After operation the extremity is suspended (Fig 526) for a period of days to prevent congestion of the wound since congestion predisposes to infection. Whether or not the plaster casing should be split must be determined by the individual surgeon If the plaster has been properly applied with adequate padding there is as a rule no need to split the casing but when there is doubt concerning its suitability not only the plaster casing

but also the padding underneath the plaster should be divided and separated in order to prevent circulatory or nerve damage

The First Dressing

Generally speaking it is not necessary to inspect the wound before the time to renew the plaster casing at the end of 10 days or 2 weeks providing that there is no undue swelling of the extremity the temperature remains normal pain diminishes steadily and the blood count remains within normal limits When the plaster casing is changed the stitches can be removed and new plaster applied with little padding This will insure a more accurate fit of the plaster

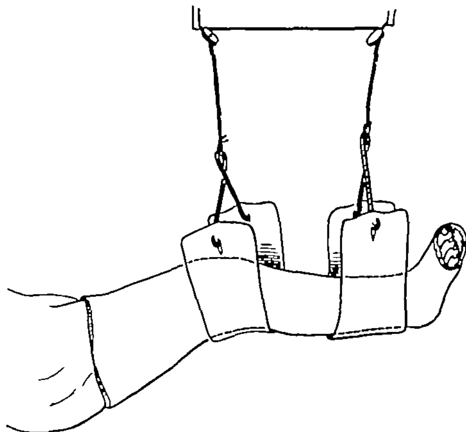


Fig 526 —Elevation of the extremity after injury or after operation will eliminate swelling and encourage wound healing

Other Forms of Internal Fixation

The Use of Screws Alone.—A single screw is useful in securing a condylar fragment or a malleolus (Fig 527) Many oblique (Fig 528) and some comminuted fractures particularly those with large butterfly fragments can be secured with screws alone and without the use of a plate In other words a large third fragment can be used for stabilizing the main fragments just as a plate would be employed. A good rule to follow in the management of any fracture is "The less hardware the better" but sufficient metal must be applied to give stability to the fracture

Parham Bands —Some surgeons find Parham bands (Fig 529) very useful particularly in the management of oblique fractures of the femur humerus and tibia. These bands are easily applied but they must be removed at the end of 6 or 8 weeks because as new bone is formed the band is covered and eventually it tends to cut through the shaft of the bone thus predisposing to refracture The bands are made of stainless steel and require special



Fig 527 —Use of a single screw for fixation of internal malleolus Left displaced fracture of internal malleolus Right reduction and bone union of fracture



Fig 528 —Use of screws alone for stabilizing long oblique fracture A, torsional fractures of tibia and fibula secondary to skiing injury B end result 1 year later complete bone union.



Fig 529 —Parham bands applied for oblique fracture of lower end of tibia

instruments for their application They may be useful when it is not possible to apply screws They may also be used in conjunction with the medullary nail in the femur or tibia to secure comminuted fragments

Treatment of Long-Bone Fractures by Medullary Nailing

The treatment of long bone fractures has been greatly enhanced during the past 20 years by medullary fixation with metallic nails pins or rods This form of treatment was used in ancient times in severe open fractures Nicolaysen in 1897 proposed such a form of treatment and Groves in 1921 advocated the use of a "long steel strut" in badly comminuted fractures However because of the poor quality of metal available the method was abandoned until in 1940 Küntscher a German surgeon showed that the method was sound and that the medullary canal could tolerate a large cylinder of steel, occupying nearly its entire diameter and still allow the fracture to heal

Medullary nailing has with considerable justification replaced plate and screw fixation in many long bone fractures particularly those of the femur The ulna fibula tibia humerus and radius have less frequently been so treated Nails of various types have been devised the original Küntscher the "clover leaf" (Fig 530 *A*) the diamond shaped nail of Hansen and Street (Fig 530 *B*) the Rush nail (Fig 530 *C*) *and the Lottes nail (Fig 530 D)* for use in the tibia

Medullary Nailing of the Femur

So-called "blind nailing" of femoral fractures where the nail is introduced in the end of the bone and driven down the canal across the fracture line into the distal fragment without exposing the fracture has largely been given up because of technical difficulties in maintaining reduction of the fracture as the nail is driven in More frequently the fracture is exposed the size of the canal measured the fracture reduced and the nail driven in either retrograde or directly down the canal

Indication for Nailing —The indications for medullary nailing of the femur are "broad or narrow depending upon the skill and experience of the surgeon with this technique and the facilities at hand" *Many surgeons will continue to use the* more orthodox methods of traction and plaster fixation or both and at times open reduction with plate and screw stabilization but in the hands of the skilled bone and joint surgeon who is familiar with the technique medullary nailing may be the method of choice

Medullary nailing is not indicated in recent fractures in young children otherwise age is not a factor This method is not necessarily the most desirable form of treatment for fresh femoral fractures but in delayed union or nonunion and in pathological fractures many believe it is the best available means of treatment Its use for early open fractures is debatable Further experience with this method may demonstrate that it has a very useful place

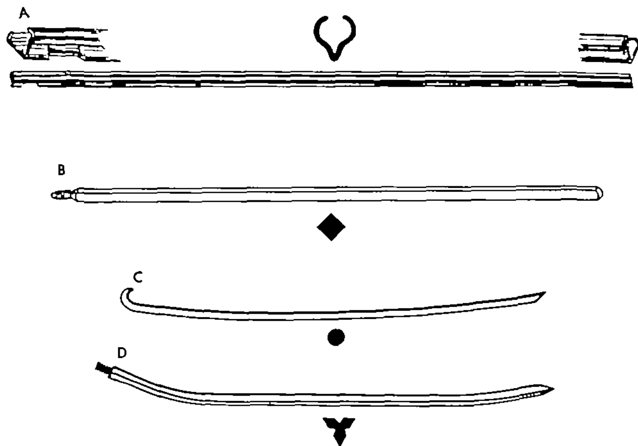
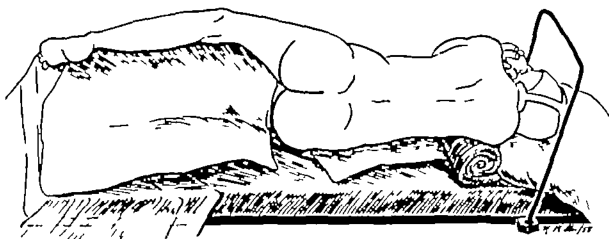


Fig 530 —Types of medullary nails longitudinal and cross-section views A, clover leaf (Küntscher) nail B Hansen Street nail. C Rush nail D Lottes nail.



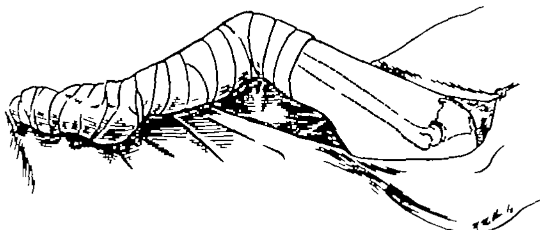


Fig 531 —Position of patient for medullary nailing of femur

in the handling of such injuries On the other hand it may be safer to allow heal ing of the soft tissues and later within a few days to insert the nail Medullary nailing can be used in femoral shortening or for correction of rotation or angulation deformity It is a tremendous aid in the management of the patient with associ ated severe abdominal and chest wounds or with extensive burns where external fixation is not possible provided of course that the patient can tolerate the major operation required for insertion of the nail. Thus the method may well play an impor tant role in war or disaster surgery

THE CLOVER LEAF NAIL.—This nail is manufactured of 18-8 S Mo stainless steel or Vitallium in diameters of 7–12 mm. and in lengths of 14–17 inches (Fig 530 *A*) It is clover leaf shaped when viewed in cross-section and it is hollow so that it may be driven over a guide rod It has tor sional strength produced by curves in both sides of a U design The nail apex has a well rounded curve to induce strength and the "eye" for extraction should be at least the diameter of the nail from the end

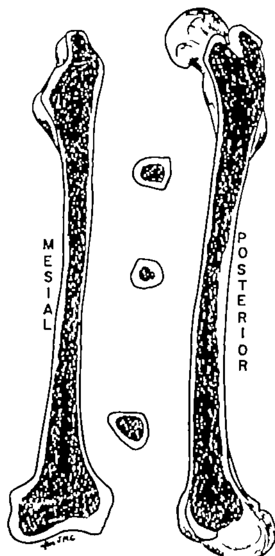


Fig 532.—Cross-section of femur The normal curve of the femoral shaft is anterior and the narrowest part of the canal is in the upper portion of the shaft of the bone (From Sofield H A. Anatomy of medullary canals Am Acad Orthop Surgeons Lect Vol VIII 1951)

The use of this nail requires direct ex posure of the fracture With the patient lying on the side opposite that of the in

jury (Fig 531) the fracture is exposed by means of an anterolateral incision (preferred for the lower half of the femur) posterolateral incision (preferred for the upper third of the femur) or directly lateral incision The fragments are mobilized The proximal fragment is brought up into the wound and the size of the canal estimated by gently inserting a medullary serted in the proximal fragment and tapped gently upward through the greater trochanter where it makes its exit and becomes subcutaneous as it is driven farther upward (Fig 533) A stab incision is then made over the guide rod point A nail of chosen diameter is inserted over the guide rod and driven about 1 inch into the cortical bone at the level of the greater tro-

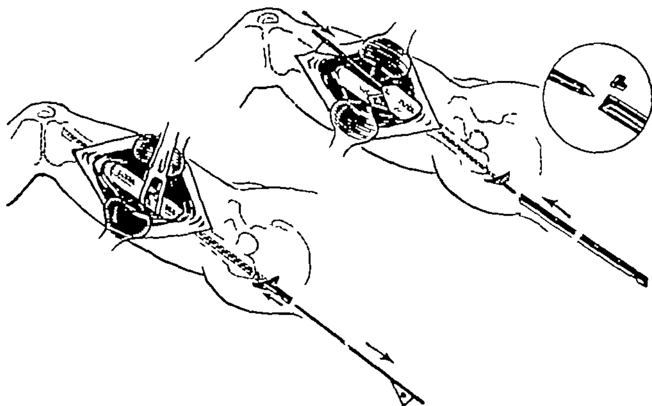


Fig 533 —Retrograde insertion of medullary nail in femur Left showing exposure of the fracture site and a guide rod introduced into the upper fragment. Right fracture reduced and held and a clover-leaf (Küntscher) nail driven over the guide rod into the shaft down to the level of the adductor tubercle

nail of known diameter The nail must fit the narrowest part of the medullary canal (Fig. 532) which is in the upper portion of the shaft On the other hand if the canal is unusually large as may be true in osteoporosis two "nested" Küntscher nails may be required to give stability to the fracture The usual diameter selected is 10 11 or 12 mm. If the fracture is an old one and the bone is sclerosed and the canal narrow at the fracture site the medullary canal must be enlarged with a reamer to accommodate the proper-sized nail

A guide rod of known length is then inchanter The guide rod is withdrawn and inserted into the hollow nail above and driven down to the fracture site The hollow nail is temporarily removed The fracture is then reduced and the guide rod is driven well into the distal fragment down to the level of the adductor tubercle Portable x ray films which include the knee joint and the fracture site are then taken in anteroposterior and lateral views and the amount of guide rod projecting above the trochanter is measured This amount is subtracted from the known length of the guide rod which gives the exact length of

nail desired. The average femur in the adult will require a nail 16 or 16½ inches in length and from 10 to 12 mm in diameter While reduction of the fracture is maintained by a bone clamp the hollow nail is inserted over the upper end of the guide rod and driven over the guide rod down across the fracture line After the may become impinged and extraction and reinsertion may be extremely difficult or impossible or it may be forced through the cortex or into the knee joint (Fig. 535) It should project no more than ½ inch above the greater trochanter

If there are large fragments in addition to the two main fragments it may be nec



Fig 534 (left) —The clover leaf (Küntscher) nail extending distally to the adductor tubercle and projecting proximally the width of the "eye" of the nail The anterior bow of the femur is eliminated to conform to the straight nail.

Fig 535 (right) —Example of a technical error in inserting the femoral medullary nail. With porotic bone the nail is easily driven through the cortex or into the knee joint. Portable x-rays taken during the operation will prevent this error

nail is well across the fracture line the guide rod may be withdrawn and the nail further inserted to the level of the adductor tubercle As the nail is driven in, the femur must be straightened to accommodate the straight nail (Fig 534) The anterior bow of the femur must be eliminated otherwise the nail will impinge against the anterior cortex The nail should be tapped gently If it is driven forcibly it essary to use supplementary fixation—either short screws through one cortex, circular wires or Parham bands—to maintain stability of these fragments The incision is closed in layers dressing applied and the leg bandaged from toes to groin. The leg is suspended in a Hodgen splint. Active muscle-setting exercises for the foot leg, and thigh are begun as soon as wound soreness subsides After wound

healing normally within a week or 10 days the leg is removed from the splint and knee motion is encouraged During the next few days sufficient muscular strength and joint mobility will be recovered to allow walking with crutches The patient's weight should be equally distributed between the injured leg and the

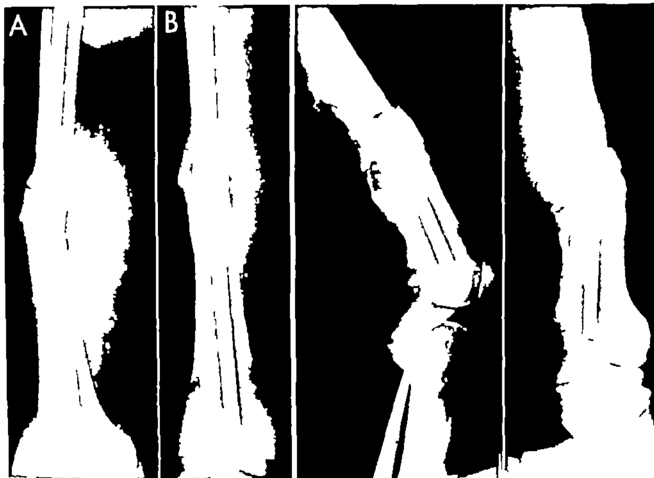


Fig. 536 (left) —A, bent medullary nail the result of discarding crutches too soon. Under anesthesia the nail and the femur were manually straightened The nail was removed without exposing the fracture site and a new nail (B) was inserted

Fig 537 (right) —Lateral and anteroposterior views of a broken medullary nail which resulted from discarding crutches too soon Both fragments of the nail were removed and another nail was inserted. In addition a walking plaster spica was applied for 4 months Bone union resulted.

crutches The use of crutches is required until solid bone union is evident by the x-ray films This will require from 6 to 12 months in most cases

Removal of the Nail —The only reasons for removal of the nail are (1) pain over the upper end of the nail which may occur if the nail projects more than about ½ inch above the greater trochanter (2) a bent nail and (3) a broken nail

Complications of Medullary Nailing

The medullary nail can be the most efficient form of internal fixation of fractures or its use may be accompanied by many technical difficulties and at times disaster Possible complications are

1 Infection.
2 Hemorrhage and shock
3 Impingement of the nail against the cortex, making insertion or removal difficult

4 Comminution of the fracture
5 Driving the nail too far into an adja cent joint, particularly in osteoporotic bone
6 Failure of the nail to fit, with resul tant rotation at the fracture site
7 Too much projection of the nail above the greater trochanter
8 Bending of the nail.
9 Breaking of the nail
10 Fat embolism—reported surprisingly rarely

Bending or Breaking of the Nail — This complication occurs occasionally and is due to excessive stress on the nail before bone union has progressed sufficiently to contribute some strength to the fracture site A fall a misstep or too early full weight bearing particularly if there is de layed union is usually responsible for this mishap Nails of small diameter i e 9 mm. or less are more likely to fail To prevent this complication the patient should walk with crutches and guarded weight bearing until union has progressed satisfactorily

Once a nail has bent it should be straightened and replaced by another preferably by a larger nail. The Hansen-Street nail will not lose much strength if bending does not exceed 30 degrees In the case of the Küntscher nail however any deformation of the nail at the point of bending results in marked loss of rigidity Except in rare instances a bent nail of any type should be considered defective and replaced by a new one Ordinarily the nail can be straightened by manipulation of the leg under anesthesia and then replaced during the same procedure through a trochanteric incision without exposing the fracture site (Fig. 536)

If the nail breaks (Fig. 537) the fracture site must be exposed and the proximal fragment either extracted through this incision or driven out through the trochanter using another nail as a driver Removal of the portion of the nail in the distal fragment may prove difficult. If the nail cannot be grasped with pliers or clamps and extracted a hole may be drilled in the exposed end using a motor-driven high speed steel drill This portion of the nail can then be removed with an extractor or suitable hook For a Küntscher nail a screw extractor or "easy out" may be used (Fig. 538) Once the old nail has been removed the fracture should be treated like any other nonunion—by fixation with a new nail and iliac grafts

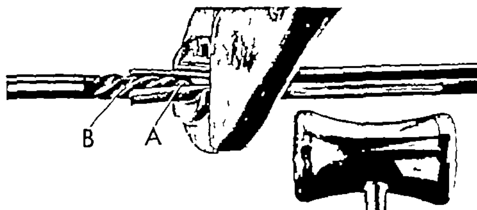


Fig 538 —The pull-out screw extractor devised by Cherry and supplemented by Southwick and Austin s vise-grip pliers This device is effective for removing broken clover leaf medullary nails Note that the base of the extractor (B) is larger than the apex (A) so that with each blow the grasp on the nail is made more secure (From Southwick, W O., and Austin G N A practical method for extracting impacted intramedullary nails J Bone & Joint Surg. 38-A 226 1956)

Sepsis Following Intramedullary Fixation —In the event of wound sepsis

following open reduction and intramedullary fixation adequate dependent drainage should be established and appropriate chemotherapy instituted Reports in the

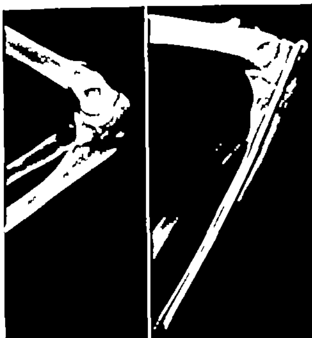


Fig 539 —Use of the Rush nail for intramedullary nailing of fracture of upper end of the ulna.

literature and experience at the Fracture Clinic of the Massachusetts General Hospital indicate that the nail should not be removed until the fracture has healed Adequate drainage and excision of scar and of sequestra should be carried out as the need arises while the fracture is healing When solid healing has occurred the nail may be removed. Although sepsis along the nail tract may occur even with drainage through the trochanteric wound the nail is as a rule well tolerated

Other Types of Medullary Fixation

The Rush Nail.—This nail (Fig 539) is made of 18-8 S Mo stainless steel Type 316 The content of this steel is given in Table 27

The Rush nail is solid cylindrical in shape and flexible It is manufactured in various lengths and diameters and is suitable for use in all long bones The principle of its medullary fixation is that of three-point pressure This type of nail is extremely useful in stabilizing fractures of the ulna and fibula It may also be used in the humerus but is less easily applied to the radius For femoral fractures two of the nails may be required

TABLE 27 —Specifications of Rush Nail

Chromium	17 54%
Nickel	12.89%
Molybdenum	2.27%
Manganese	1 67%
Carbon	0 059%
Silicon	0 50%
Phosphorus	0 024%
Sulfur	0 020%

When inserting the Rush nail it is usually advisable to expose and reduce the fracture and then make a small drill hole in either the distal or proximal end of the broken bone The nail can then be gently



Fig 540 —Use of the Lottes nail for fixation of tibial fracture

tapped into the shaft to the fracture site the fracture reduced and held with a bone clamp and the nail further gently tapped or guided with strong pliers into the other fragment If impingement is encountered the nail should be rotated back and forth as it is inserted into the canal. It should be driven well into the bone so that the hook on the proximal end can be locked into cortical bone

THE LOTTES TIBIA NAIL —Another type of nail, designed by Lottes of St. Louis is multiple segmental fractures" (see Chapter 28 on Fractures of the Tibia and Fibula) It has also been employed in selected open fractures and in cases of delayed union or nonunion of the tibia.

In cases of nonunion of long bones in close proximity to joints the form of treatment used occasionally at the Fracture Clinic of the Massachusetts General Hospital has been to introduce a medullary nail through the adjacent joint. This treatment has been used in fractures of the humerus when a Rush nail has been driven down through the humeral head In 6 cases of prolonged nonunion of the tibia a Küntscher nail was introduced through the knee joint. This procedure was used only in extreme cases when no other form of internal fixation would suffice (See Chapter 5 on Delayed Union and Nonunion of Fractures)



Fig 541 —Restoration of elbow motion after olecranon excision following old fracture A, olecranon fracture which had been treated by catgut suture 18 months previously Motions were 15 degrees fixed flexion to 60 degrees further flexion B 2 months after olecranon excision. Motions were 5 degrees fixed flexion further flexion 145 degrees—essentially normal. C, the excised olecranon.

used for tibial fractures It is made of 18-8 S.Mo stainless steel, is triflanged and is curved to allow its insertion at the level of the tibial tubercle (Fig 540) It has a diameter of 3⁄8 inch and is available in lengths of 9½–14 inches the lengths varying by ½ inch

Lottes usually avoids exposing the fracture by carrying out a closed reduction and then with the patient's knee flexed over the end of the operating table he drives the nail across the fracture line well into the distal fragment The nail can be used for "any fracture in the middle one-third or upper portion of the tibia and for

FRACTURES TREATED BY EXCISION OF FRAGMENTS

The patella and the olecranon perform similar functions in the knee and elbow

respectively and when they are fractured they may at times be treated similarly—that is by excision (see Chapters 27 and 19) The severely comminuted patellar fracture is best managed by excision of all fragments and suture of the quadriceps and patellar tendons When there is a transverse fracture the surgeon may elect to excise the smaller fragment and suture the tendon to the remaining larger fragment

Olecranon fractures particularly in older adults are effectively managed by excision of the fragment and suture of the triceps tendon to the ulna if at the time of operation passive displacement of the joint is not possible Excision of the olecranon is followed by early use of the elbow and a good return of function (Fig 541) Treatment by excision may also be used for the following the internal humeral epicondyle which has been pulled into the elbow joint old displacements of the outer or inner end of the clavicle if painful the ununited spinous process of a vertebra and an ununited neck or base of the fifth metatarsal.

Much has happened as a result of the operative treatment of fractures in this century to condemn the procedure in many instances The unsatisfactory outcomes have largely been due to lack of fundamental training and judgment on the part of the surgeon resulting in poor selection of cases and faulty operative technique If the surgeon is properly trained and exercises careful judgment in the selection of cases this form of fracture management has much to recommend it. But no surgeon should operate on a fracture unless he and his assistants are properly trained the proper instruments are available the operating room is adequate sterilization is trustworthy and the patient s general condition is satisfactory

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33 

Treatment of Open Fractures

SURGICAL MANAGEMENT

General Principles

During the past 30 years the management of open fractures has passed through several distinct phases Following World War I open fractures were treated routinely by irrigation with Dakin s solution and the majority of them were left open or partially closed around tubes Although healing was slow the incidence of invasive sepsis was also low Beginning in the 1930 s an increasing number of open fractures were stabilized with plates and screws This prompted initial closure of the wounds which was followed by an increase in the incidence of sepsis The factors that seemed directly related to the rise in septic complications were

1 The poor quality of steel used for fixation Electrolytic reaction was a serious complication, causing local necrosis and frequent breakage of the metal

2. Inadequate debridement as compared to present-day techniques

3 The lack of chemotherapeutic and antibiotic coverage

4 Primary closure of wounds over devitalized tissue

With the introduction of improved metal during World War II with chemotherapy and with a definite improvement in surgical techniques and supportive treatment for the patient the incidence of severe septic complications has steadily decreased (Table 28)

The problem of infection remains however and is a very serious one In considering the problem the following factors seem important enough to be emphasized at the beginning of this chapter

1 The soft tissues of an open wound should be restored to normalcy as rapidly as possible

2 The fractured fragments should be stabilized adequately either with external support or with internal fixation.

3 All devitalized tissue and foreign material should be removed from the wound

4 The blood supply of the soft tissues covering bone should be disturbed as little as possible

5 An open wound should not be closed under tension Relaxing incisions or rotating flaps will eliminate suture line tension

6 Secondary closure of the wound is a safe procedure and should be used when indicated

7 Congestion and tissue edema of the extremity should be avoided This can be accomplished by good plaster technique and immediate elevation of the extremity following debridement

Treatment

The treatment of open fractures may be divided into two distinct phases the *early* or emergency phase and the *late* or delayed phase The early phase includes the initial emergency care and operative debridement. The late phase includes secondary closures of the wound operative procedures for septic complications plastic procedures or bone grafting The extent of the late phase depends on the severity of the injury and the degree of success attained in the early phase

In the Emergency Room

Many factors bear directly on the success of early treatment. Of great importance is the organization of the emergency ward as to its personnel and equipment. Delays must be avoided. The problems of disposition coverage and responsibility of the injured patient can be determined in advance Established routines and team work mark an efficient emergency ward. The various hospital departments such as x ray laboratory and operating sections must be organized to give priority to open fractures

The treatment administered in the emergency room consists of the following (see also Fig 542)

Evaluation of the Patient —A rapid but careful examination of the patient is carried out The degree of shock is estimated the patient s airway checked and the presence of intracranial thoracic or intra abdominal injuries determined The injured extremity is examined regarding bleeding and the presence or absence of vascular or nerve injury

Relief of Pain.—After a general examination of the patient the proper analgesic can be administered. Intravenous barbiturates are very effective and have many advantages over intramuscular narcotics (see Chapter 9 Early Examination and Treatment of the Injured Patient) On admission to the emergency room the patient is placed on a canvas-covered lead pipe frame (Fig 542 *A*) This eliminates any further moving of the patient until treatment is completed and the patient is in bed The frame can be lifted to the x ray table to the operating room table or to the bed with little disturbance to the patient

Care of the Wounds —For fractures of the knee leg or foot the pillow splint (Fig 542 *B* and *C*) has many advantages A sterile half sheet is placed over the pillow the extremity with clothes removed is then placed on the pillow Bleeding vessels are clamped or ligated a sterile gauze fluff is placed in the wound and the sterile sheet and pillow are lightly closed around the extremity by means of gauze bandage or webbing Sideboards may be used The

TABLE 28 —Incidence of Sepsis in 262 Open Fractures 1930–55 (from Follow up Studies)

	1930–45 (132 Cases)	1945–55 (130 Cases)	Total (262 Cases)
Upper extremity	9% (5/54)	0% (0/37)	5% (5/91)
Lower extremity	32% (25/78)	13% (12/93)	22% (37/171)
Total incidence	23% (30/132)	9% (12/130)	16% (42/262)
Gas gangrene	2.3% (3/132)	0% (0/130)	1 1% (3/262)
Amputation due to sepsis	5.3% (7/132)	1.5% (2/130)	3 4% (9/262)
Death due to sepsis	1.5% (2/132)	0% (0/130)	0.8% (2/262)

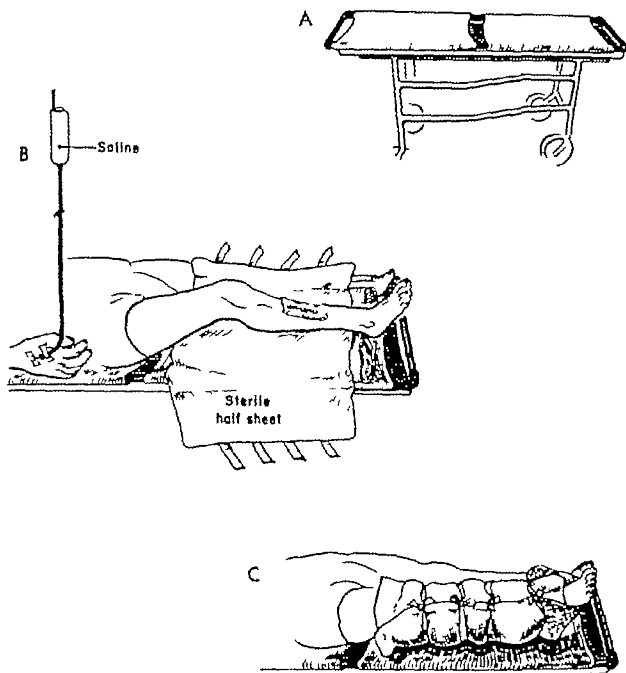


Fig 542.—Emergency room treatment A, canvas-covered lead-pipe frame on which patient is transported B emergency care The condition of the patient should be evaluated and the following done The leg should be supported by pillows bleeders ligated sterile gauze placed in wound and needle placed in vein for blood typing intravenous fluids, and medication. C, transportation of patient from emergency room to x-ray department or operating table.

pillow splint gives uniform support and elevation to the extremity and its softness is comforting The evenly applied pressure decreases hemorrhage and edema pain is markedly relieved X rays can be taken very satisfactorily through the pillow

SUPPORTIVE TREATMENT —When severe open fractures are admitted to the emergency room a needle is introduced in the patient's arm or hand vein. Blood is drawn for typing and medications may be administered and fluids given as indicated The difficulty and delay in venipuncture after shock occurs are thereby eliminated Initial chemotherapy tetanus antitoxin or toxoid are administered as indicated

AVOIDANCE OF DELAY —In many instances very valuable time may be saved for seriously injured patients if they are taken directly to the operating room by passing the x ray department Portable x ray films may be made in the operating room.

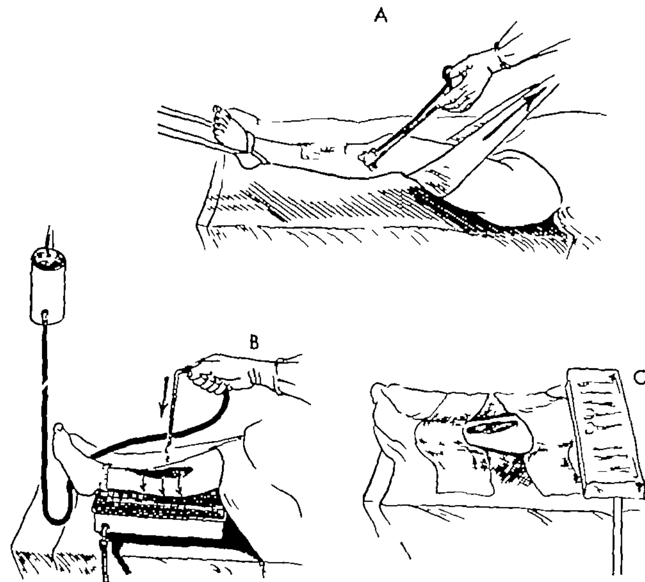


Fig. 543 —Operating room treatment. A, skin preparation. To protect wound from solutions, sterile gauze should be placed in the wound. B debridement Foreign bodies and necrotic tissue should be removed by saline irrigation and gentle swabbing of tissue with saline sponge C surgery The drapes and instruments should be changed completely the fracture reduced and internal fixation used if necessary

In the Operating Room

In the operating room the skin should be cleansed A dry gauze fluff placed in the wound and changed frequently during the skin preparation will protect the muscles and soft tissues from antiseptic solutions (Fig 543 *A*)

DEBRIDEMENT —Whenever possible debridement of an open fracture should be performed in a fully equipped operating room In major cases it is well to have two changes of drapes and instruments An irrigating basin (the Marble type) will prove very useful (Fig 543 B)

The extremity should be carefully supported during surgical preparation of the skin. A Kirschner wire introduced through

the os calcis for tibial fractures or through the tibial tubercle for femoral fractures is a very helpful means of supporting the extremity It also eliminates the use of supporting hands near the area that is being prepared

Sterile drapes are applied to the extremity and the initial debridement is carried down to the deep muscles The drapes are then changed (Fig 543 C) and with fresh instruments debridement is completed If internal fixation is necessary to hold the fracture in a reduced position it is done at this time Adequate plaster or other splinting is applied and the extremity is elevated immediately after the operation in order to lessen swelling and pain (Fig 544 E)

SPECIFIC TECHNICAL STEPS —In addition to the following procedures see Figure 544 on wound management

Skin —As a rule it is best to freshen the skin edges of an open fracture by sharp dissection The wound should be adequately exposed In doing this the wound may be developed in line of the extremity Old scars or incisions should not be crossed particularly in the lower third of the leg because of the possibility of necrosis or slough Such scars are best included in the exposure incision Skin trauma must be reduced to a minimum It is well to avoid the use of towel clips or skin clips The skin should be undermined as little as possible since undermining reduces blood supply In those instances in which the skin is seriously devitalized by abrasion or pressure local resection of the skin should be performed and a fresh split skin graft applied A potential source of slough and infection is thereby eliminated

Muscles —Foreign bodies and devitalized soft tissues are carefully removed by forceps and sharp dissection The application of large warm saline compresses to the wound will help evaluate the vitality of muscle tissue Normal muscle is contractile bleeds freely and has a characteristic pinkish appearance Devitalized or necrotic muscle should be removed by sharp dissection. Excessive amounts of saline irrigating solutions should not be used Irrigation of muscle beds with "quarts" of saline in order to "clean" the field may very well remove the normal protective elements of the tissue and actually devitalize the superficial muscle layers Careful swabbing of the muscles with warm saline gauzes and direct removal of soiled tissue with forceps and scissors or a knife are more reasonable procedures. Irrigation of the wound in moderation is indicated

When there is doubt regarding the completeness of the debridement or of the condition of the wound warm saline gauzes should be lightly introduced into the wound and kept moist with onlying catheters A secondary debridement may be performed 5–8 days later with closure of the wound at that time

Wounds of large muscle areas as in the thigh should have a posterior stab wound for adequate drainage The wick may be removed after 2–3 days This will aid in eliminating accumulations of blood clots in dead spaces or muscle planes Accumulated blood in dead spaces is an excellent culture medium for bacterial growth.

Bone —Exposed bone is washed carefully with saline sponges and all foreign material removed either by forceps or rongeurs or by saline irrigation It is most important to leave intact the protective periosteal and muscle covering of bone in open fractures Care should be used in mobilizing or reducing the fracture Bone fragments in the wound without periosteal attachment should not be discarded These fragments when carefully cleansed and replaced in the fracture line will function as grafts and be reconstituted into the healing fracture This precaution may very well prevent a subsequent operation for nonunion

Fixation —Fractures are either stable or unstable This is a very important differentiation and should be appreciated by the surgeon A stable fracture may be supported very effectively with a well applied

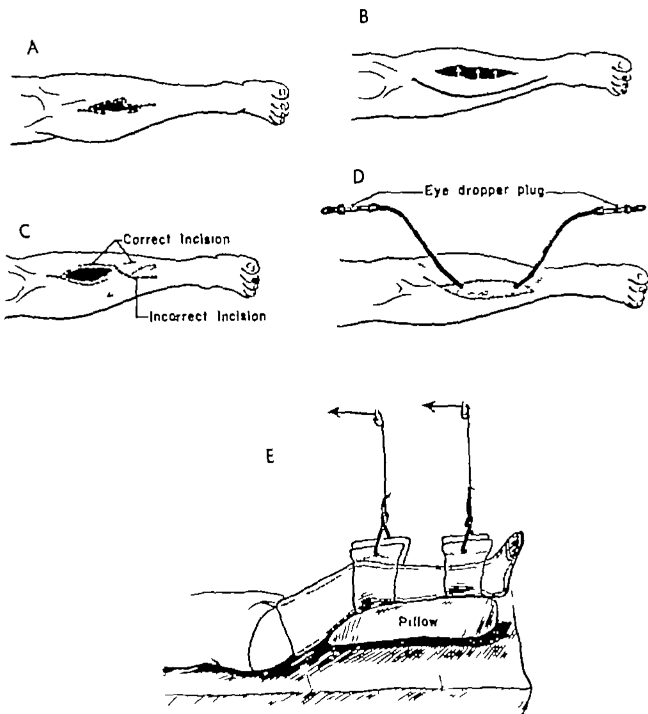


Fig. 544.—Wound management A, preparing for surgery by enlarging wound in line of extremity and excising the edges of the skin B tension avoided by using relaxing incision when necessary C, crossing of old scars avoided. D wound left open and lightly packed with saline gauze fluff when viability of tissues is in doubt. E, immediate postoperative elevation to eliminate congestion and lessen pain

plaster cast As a rule neither internal fixation nor traction is indicated in a stable fracture

It is generally agreed however that an unstable fracture in which displacement and angulation occur may be associated with increase in local circulatory stasis blister formation edema, and diminished tissue vitality These factors definitely lower the local resistance to infection. Adequate stability may be accomplished in unstable fractures with plaster of paris Traction and suspension have proved very satisfactory in many instances The question of whether or not internal fixation should be employed in open fractures is controversial and deserves consideration The application of plates and screws to stabilize a fracture necessitates freeing up local muscle attachments and periosteum This undoubtedly lowers the local blood supply to the bone fragments Consequently the risk of applying a plate to an open fracture must be weighed against its advantages Multiple screw fixation is applicable in long oblique fractures and may require less periosteal stripping The use of intramedullary fixation has definite advantages and definite risks

The *advantages* of intramedullary fixation in open fractures are:

1 Minimal wound exposure and disturbance of soft tissue at the fracture site Periosteal stripping is not necessary

2 Excellent fixation in selected bones such as the femur tibia and ulna This will lessen tissue stasis and congestion thus increasing the resistance of local tissues to infection

3 Early mobilization in many cases

The *disadvantages* of intramedullary fixation in open fractures are

1 The possibility of introducing bacteria into the medullary cavity of the long bone

2 Mechanical difficulties in the use of intramedullary fixation

Experience with intramedullary fixation in open fractures at the Massachusetts General Hospital Fracture Clinic has been satisfactory There has been rapid subsidence in pain swelling and soft-tissue reaction and no serious sepsis Local tissue vitality has been improved A safe and reasonable procedure is First allow the wound to heal, and then apply internal fixation if indicated

It must be emphasized again however that before any type of internal fixation is used in open fractures the surgeon must be satisfied that he is sufficiently trained in the use of such equipment and that he has adequate assistance and the necessary instruments for the operation

The patient's general condition must also be carefully considered Most of the patients with open fractures are in some degree of shock and may have associated injuries They should not be subjected to prolonged procedures unless their condition is satisfactory (See Chapter 9 Early Examination and Treatment of the Injured Patient)

Wound Closure —In civilian hospitals the majority of open wounds are debrided and closed primarily Wounds produced in combat by gunshot or shrapnel and by high explosives present a different problem Combat wounds are as a rule deep with a relatively small wound of entrance and a large wound of exit. An appreciable amount of muscle and bone injury is produced and foreign material is frequently carried deep within the tissue Delayed or secondary closure has proved to be the safest procedure in gunshot wounds (Fig 544 D)

Peacetime open fractures however are more limited in their area of trauma. Open fracture of the tibia is the most common open fracture and since the tibia is a subcutaneous bone this fracture presents a rather superficial wound Primary closure is usually justified Secondary closure should be used however when there is any doubt of the viability of the tissues or extent of injury

The degree of initial tissue injury abrasive skin burns undermining of the skin or loss of skin or of subcutaneous tissue must be carefully noted and evaluated Necrotic

skin areas are best excised and covered with a split-skin graft initially When it is necessary to put undue tension on the su ture line relaxing incisions are indicated In some instances at the Massachusetts General Hospital Fracture Clinic the subcutaneous tissues were closed but suturing of the skin was omitted

The method of wound closure must be left to the judgment and experience of the operating surgeon

Dressings —The initial dressing of an open fracture wound which has been su tured consists of several layers of evenly applied soft gauze dressing Next the ex tremity is wrapped with an adequate amount of sterile sheet wadding. Plaster is then applied with careful molding of the cast. Gauze bandage if used will frequently become tighter after plaster is applied and may cause serious pressure areas over the dorsum of the foot or shin The use of gauze bandage here is to be con demned Immediately after the plaster is applied the extremity is elevated by means of double slings (Fig. 544 *E*) in this way postoperative edema is avoided and the patient is much more comfortable

The Unconscious Patient —Should debridement of a fresh open fracture be per formed on an unconscious patient? This is a controversial subject. The decision to debride should be made after consultation between the fracture neurological and anesthesia services. The two main consid erations are the cause of the patient s unconscious state and the severity of the open fracture.

In the experience of the Fracture Clinic of the Massachusetts General Hospital a 12–24-hour delay in debridement has not resulted in a significant increase in septic complications On the other hand an un conscious patient whose condition is not deteriorating may stand debridement very well if adequate oxygen is administered Consequently it seems safe to delay debridement a reasonable period in order to evaluate the cause of unconsciousness An end point arrives when the risk of delay in the debridement must be weighed against the risk of performing surgery on an unconscious patient An adequate debridement performed under careful anesthetic supervision may be the reasonable compromise when unconsciousness ex tends beyond a safe period

Complications

A study of the complications arising in the treatment of open fractures was made based on 262 patients followed in the Frac ture Clinic of the Massachusetts General Hospital over the past 26 years (open frac tures of the phalanges the metacarpals the metatarsals and skulls were not in cluded) The conclusions derived from the study follow

Septic Complications

The following definite factors seem to be related to the development of septic complications

Severity of the Injury —The severity of the septic complication was directly related to the severity of the open wound (Fig 545)

Open wounds were graded as mild, mod erately severe and severe Likewise the degrees of septic complications were graded as mild moderately severe and severe The criteria for estimating the severity of the open wound and the severity of the postoperative septic complications follow The "mild open wound" is the puncture wound The "moderately severe wound" includes larger wounds with appreciable exposure of the fracture site but in which the soft tissues are in good con dition and the degree of wound soiling is not extensive The "severe wounds" in clude those in which there is necrosis of the soft tissues and in which dirt or foreign material is embedded in the soft tissues or the bone fragments The "mild septic com plication" is the superficial wound slough or abscess down to the muscle layer which healed within a relatively short time The "moderately severe complications" are those in which the fracture site was in

use only 31 per cent had such complications.

BACTERIOLOGICAL AND ANTIBIOTIC CONSIDERATIONS

One of the objectives in the management of open fractures is the prevention of local and invasive infection The former may vitiate an otherwise good result, and the latter may result in a fatality In order to approach the problem of intelligent prophylaxis and therapy of infection a knowledge of the bacteriology of traumatic wounds is essential.

BACTERIOLOGY

The bacteria most likely to be found in traumatic wounds are those which occur commonly on the surface of the skin clothing or dirt of the environment The enormous literature on the bacteriology of war wounds in World War II is important in that attention was directed to the frequency with which gas-producing anaerobes could be cultured in deep puncture wounds and in wounds associated with muscle trauma and foreign bodies

Rustigian and Cipriani studied the flora of 38 war wounds incurred during the Italian campaign in World War II They isolated 214 types of bacteria—some invasive and toxigenic others proteolytic wound pathogens and saprophytes The most frequently encountered bacteria were beta hemolytic streptococcus Staphylococcus aureus and albus enteric streptococci clostridia Proteus Pseudomonas and coliform bacilli Less frequently encountered were undifferentiated streptococci anaerobic streptococci micrococci bacteroides diphtheroids and unclassified bacilli The anaerobic environment is emphasized by the finding that 45 3 per cent of the organisms were obligate anaerobes

Although war wounds may be more extensive more grossly contaminated and treated later than civilian injuries Rustigian and Cipriani s careful study indicates the variety of organisms that may be encountered Pulaski Meleney and Spaeth made cultures from 200 previously untreated civilian wounds the majority of which were seen within ½ hour after their occurrence They were able to isolate 606 species of bacteria averaging approximately 3 species per wound No wound was free from bacterial contamination. Even 21 6 per cent of the so-called "clean cases harbored anaerobes compared with 43 5 per cent of the "dirty" cases The longer the time before therapy the higher the percentage of anaerobes The most frequently encountered organisms were Staph aureus, 52 per cent Staph albus 81 per cent hemolytic streptococcus aerobic 12 per cent clostridia, 11 per cent in clean wounds and 34 6 per cent in dirty and enterobacilli 24 per cent Most of the clostridia were Bacillus welchii. The ubiquity of B welchii in the human environment was dramatically demonstrated by Altemeier and Furste who found viable spores in 15 samples of dirt collected from the major intersections of streets in Cincinnati Ohio

ANATOMICAL CONSIDERATIONS

The organisms responsible for invasive infection are the hemolytic streptococcus, Staph aureus and the toxigenic clostridia. The mere presence of these organisms in wounds does not necessarily indicate clinical invasive infection since the organisms may be responsible for localized suppuration only

Of all organisms the hemolytic streptococcus is most readily able to produce an invasive infection from a cleanly incised wound Staphylococcus aureus invades less readily from clean wounds but in the presence of fracture devitalized tissue wound exudate and blood may proliferate rapidly and invade

Approximately 80 per cent of the cases of clostridial myositis (gas gangrene) are due to B welchii. The average incidence of B welchii in 3 027 civilian and military wounds was found to be 14 7 per cent In contrast to this is the low incidence of gas gangrene—only 1 76 per cent in 187

936 open wounds Repeated studies have shown that there may be no difference between the bacterial flora of wounds that develop gas gangrene and the flora of those that do not These considerations indicate that humoral factors and more well-defined local ones determine whether gas gangrene develops or localized suppuration occurs

Clostridial myositis is more likely to develop in the presence of the following

1 Devitalized muscle especially of a lower extremity Healthy tissue has a remarkable capacity for destroying bacteria

2. Interference with blood supply either as a result of injury or by the prolonged application of tourniquets North noted that in 72 per cent of his patients with gas gangrene there was damage to a major vessel.

3 Delay in surgical therapy Levaditi and his colleagues have shown a fourfold increase in incidence among soldiers when surgical therapy was delayed

4 Presence of foreign body such as dirt, clothing gravel, etc. which seems to predispose to the development of infection

5 Fractured bone The association of gas gangrene with fracture is well known In the American Expeditionary Force in World War I there were 1 329 cases of gas gangrene in 25,272 cases of fracture of bone—an incidence of 5 2 per cent In 128 000 wounds of soft parts the incidence was 1 1 per cent. Millar studied 607 cases in civilian life and found that 60 9 per cent were associated with fracture

In addition to the foregoing potentially invasive bacteria, a larger number of non-invasive organisms may be present in wounds. These have been divided into wound pathogens and commensals These organisms are entirely dependent on devitalized tissue cellular debris blood clot and wound exudate for their proliferation. Wound pathogens such as Clostridium sporogenes Bacillus pyocyaneus and Aerobacter aerogenes as well as a host of others produce proteolytic enzymes responsible for septic decomposition of devitalized tissue These organisms may be locally invasive and responsible for a local necrotizing action The commensal bacteria such as the coliform organisms enteric streptococci, and Staph albus possess no proteolytic activity toxigenicity or ability to invade

The conditions favorable for the development of gas gangrene are also favorable for the proliferation of Clostridium tetani and the development of tetanus in the susceptible patient Unlike gas gangrene however tetanus may occur as a result of a trifling cut or scratch if spores are implanted and anaerobic conditions exist

Role of Debridement

As noted previously with the exception of the hemolytic streptococcus and Staph aureus the organisms likely to be found in open injuries require for their prolification the presence of necrotic or devitalized tissue blood clot and transudate Masses of dead muscle or the presence of blood clot or foreign body will almost certainly result in both aerobic and anaerobic infection. The importance of early and adequate debridement as a prophylactic and therapeutic measure for removing dead tissue in which bacteria capable of producing local and invasive infection flourish cannot be overestimated.

Role of Antibiotics

The role of antibiotics must be considered as adjunct therapy not as a substitute to adequate sound surgical measures Prior to the antibiotic era the chief concern of the surgeon was the presence of beta hemolytic streptococci in wounds and the possibility of overwhelming invasive infection. Fortunately the beta hemolytic streptococci are universally susceptible to penicillin as well as to most of the other antibiotics As a result septicemia cellulitis and lymphangitis due to this organism have virtually disappeared

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As noted previously with the exception of the hemolytic streptococcus and Staph aureus the organisms likely to be found in open injuries require for their proliferation the presence of necrotic or devitalized tissue blood clot and transudate Masses of dead muscle or the presence of blood clot or foreign body will almost certainly result in both aerobic and anaerobic infection The importance of early and adequate debridement as a prophylactic and therapeutic measure for removing dead tissue in which bacteria capable of producing local and invasive infection flourish cannot be overestimated

Role of Antibiotics

The role of antibiotics must be considered as adjunct therapy not as a substitute to adequate sound surgical measures Prior to the antibiotic era the chief concern of the surgeon was the presence of beta hemolytic streptococci in wounds and the possibility of overwhelming invasive infection Fortunately the beta hemolytic streptococci are universally susceptible to penicillin as well as to most of the other antibiotics As a result septicemia cellulitis and lymphangitis due to this organism have virtually disappeared

Staphylococcus aureus because of its increasing resistance to penicillin has become increasingly more of a problem In 1 year at the Massachusetts General Hospi

tal, 71 per cent of the strains of Staph. aureus cultured from wounds were found to be resistant to penicillin, 41 per cent to streptomycin 31 per cent to Terramycin® 25 per cent to Aureomycin® 31 per cent to tetracycline 3 per cent to erythromycin and 2 per cent to Chloromycetin® These organisms were cultured from wounds the majority of which had become septic despite antibiotic therapy The incidence of resistant strains in the wounds prior to instituting antibiotics prophylactically is unknown since routine pretreatment cultures are not usually performed at the Massachusetts General Hospital. Presumably the sensitivity to penicillin is greater than the foregoing figures indicate because septic complications are not so high as the resistance of the organisms would lead one to anticipate

Some surgeons prefer not to employ antibiotics prophylactically relying instead on local resistance and circulating antibodies when injury is mild Because the hemolytic streptococcus is a ubiquitous *organism and may invade from clean* wounds such a possibility must be accepted when antibiotics are not employed The virtual elimination of the hemolytic streptococcus as an invasive organism is ample evidence of the value of prophylactic antibiotics in open injuries

A review of the organisms likely to contaminate open injuries indicates that many are not susceptible to any one antibiotic or to a combination of antibiotics The success of therapy however indicates that sterilization of the wound before closure is not only impossible but unnecessary It is apparent that living tissue has marked powers of resistance to infections When open injuries are seen early when muscle damage is slight to moderate and when adequate debridement can be performed 300 000 units of aqueous procaine penicillin and 0 5 Gm of streptomycin intramuscularly every 12 hours is recommended

If muscle damage is moderate and debridement delayed but adequate 500 000 units of aqueous soluble penicillin and 0 25 Gm. of streptomycin intramuscularly every 6 hours is recommended.

When injuries are seen late but before established suppuration, when muscle damage is extensive or when adequate debridement is impossible and blood supply compromised 1 000 000 units of penicillin and 0 5 Gm. of streptomycin is administered every 6 hours. It should be stressed that parenterally administered antibiotics reach injured areas via the circulation. If the circulation is compromised inadequate concentrations may reach the contaminated area despite large parenteral doses

Because of its unpredictable absorption oral penicillin cannot be relied on to give adequate blood levels Its use is not recommended in open injuries Broad-spectrum antibiotics have been reserved for therapy of established infections or when allergy to penicillin exists Although many papers have appeared showing that one or another of the broad spectrum antibiotics are effective as prophylactic agents the results are no better than the combination of penicillin and streptomycin

Administration of antibiotics used prophylactically is discontinued on the fifth day if the wound is closed and there is no evidence of sepsis.

When antibiotics are employed the cardinal signs of infection may be suppressed —only to appear again when they are discontinued The lag may be a few days to several weeks before local and general signs become manifest. This should be kept in mind when the patient develops a febrile episode after discharge from the hospital

Role of Antisera

Since tetanus is always a possibility in open wounds a booster dose of tetanus toxoid should be given if the patient has been immunized within 3 years If not tetanus antitoxin is administered. In recent years the recommended prophylactic dose of antitoxin has increased 10 000

units has been recommended in all open fractures rather than the usual 1 500 units for minor injuries Such a dose will give effective blood levels for 4–6 weeks

There is little clinical evidence that gas-gangrene antitoxin prevents lessens the severity or reduces the mortality from clostridial myositis It is used mainly because surgeons are afraid not to use it rather than because of definite proved value

Therapy of Established Wound Infections

Acute Aerobic Pyogenic Infection — The therapy of wound infection following open injuries almost invariably includes wound revision The invasive elements of the infection are first brought under control by antibiotic therapy Revision is then performed under antibiotic protection

The proper selection of antibiotics should rest on culture and sensitivity of the infecting organisms but selection may not be possible if the wound is closed and there is no drainage to culture In most cases when culture can be performed the offending organism will be found to be Staph aureus alone or in combination with gram-negative bacilli

As previously noted at the Massachusetts General Hospital during 1 year it was found that 98 per cent of the strains of Staph. aureus tested were sensitive to Chloromycetin® and 97 per cent to erythromycin. The gram negative bacilli varied widely in their sensitivity However Chloromycetin® was found to be most effective against Escherichia coli Bacillus proteus and B pyocaneus—organisms that are most likely to be found in combination with Staph aureus in wound infections

When the picture of an acute pyogenic infection presents itself it may be expedient to institute antibiotic therapy before obtaining specific bacteriological information regarding causative organisms and sensitivity tests since such tests usually require 36 hours to perform Also in closed infections where no material can be obtained for culture antibiotic therapy should not be delayed prior to wound revision Chloromycetin® alone or in combination with erythromycin affords broad antibacterial coverage and accordingly is recommended when the bacteriology and sensitivity of specific organisms are unknown

Erythromycin should not be used alone because organisms may become resistant to it very rapidly According to a study at the Massachusetts General Hospital Staph aureus does not appear to be increasing in resistance to Chloromycetin® as is the case with other broad-spectrum antibiotics The wide coverage against organisms found in wound infection the ease of tolerance and the failure to acquire resistance makes Chloromycetin® the agent of choice in the treatment of wound infection

Whereas antibiotics are used for only a few days in prophylaxis in therapy they are used for weeks If Chloromycetin® is employed the blood leukocyte count should be checked every 5–7 days in order to anticipate any bone-marrow depression, although it is now apparent that this is a very rare complication

The dose of Chloromycetin® in adults is 1 0–2 0 Gm in four divided doses orally If intravenous or intramuscular administration is indicated 0 5 Gm every 12 hours is used Similar doses are employed with erythromycin and other broad spectrum antibiotics

Whenever localized suppuration is present, the possibility exists that bacteria may enter the blood stream directly or via the lymphatics This is manifest by a shaking chill and a rapid rise in temperature Metastatic septic foci may occur as a result of bacteria being carried by the blood stream from the original area of infection If the local source of suppuration can be eliminated the bacteremia should disappear unless the metastatic areas serve as a secondary distributing focus

If the train of events indicates that a bacteremia is present antibiotic therapy should be instituted without delay as soon

as blood cultures are drawn The agent of choice is Chloromycetin® and erythromycin in combination One gram of each in four divided oral doses should give adequate and broad coverage Antibiotic revision may be necessary after the sensitivity of the organisms isolated from the blood is known Wound revision is performed under antibiotic protection

Localized Anaerobic Infection — When debridement is delayed as may be the case in war wounds septic decomposition of devitalized tissue may occur Such decomposition may be associated with gas in the tissues and foul odor Anaerobes such as the proteolytic Cl. sporogenes bifermantans and putrificum may be present. In the absence of concomitant aerobic infection there is only mild toxemia. There is no invasion by anaerobes their prolification occurs only in the devitalized tissue within the wound

Prompt and adequate debridement and the use of antibiotics as outlined above should prevent this type of infection from occurring

Anaerobic Cellulitis —In certain cases locally multiplying anaerobes may invade tissue spaces such as fascial planes or the septa between muscles Large amounts of gas may be produced which escapes into the tissue spaces This infection has been termed "anaerobic cellulitis" It appears later than gas gangrene (3–4 days or more later) and the appearance is less precipitous There is very little systemic reaction If there is a large amount of gas and slight toxemia anaerobic cellulitis rather than gas gangrene is present

It is important that anaerobic cellulitis and gas gangrene be differentiated so that the more radical surgical procedures such as unnecessarily extensive debridement and amputation be avoided Debridement drainage of fascial planes and antibiotic therapy usually give satisfactory results 500 000 units of aqueous penicillin and 0.25 Gm of streptomycin intramuscularly every 6 hours is advised

Clostridial Myositis —Gas gangrene or clostridial myositis is the most serious of all wound infections and must be considered a surgical emergency It usually appears within the second or third day after injury is always sudden in onset and may lead to death in 24 hours

It should be stressed that gas gangrene is a clinical diagnosis and that the presence of clostridia in the wound does not necessarily mean an invasive infection The sudden development of severe pain in the wound with or without a sharp rise in temperature elevated pulse rate toxemia, and deterioration of the patient within a few hours should lead to prompt investigation Gas formation occurs late and may be minimal

If extensive debridement of involved muscle groups is necessary or if the infection is widespread amputation may be essential in order to prevent a fatality In such a case penicillin should be given in large doses (1–2 million units) every 3 hours intramuscularly or by constant intravenous drip In addition 0 5 Gm of Chloromycetin® intravenously or intramuscularly every 12 hours is advisable in view of the probability of a mixed infection being present.

Gas gangrene antitoxin is of doubtful value in therapy and has for the most part been abandoned

Chronic Pyogenic Infection —When chronic pyogenic infection occurs it will be found that in the majority of cases initial therapy has not or could not be correctly applied Necrosis slough and any foreign bodies or blood clots must be removed. Any collection of pus must be drained and sinus tracts excised under antibiotic protection The choice of an antibiotic depends on the sensitivity of the organisms present As with acute pyogenic infection it will be found that the Staph aureus alone or in combination with gram negative bacilli will be responsible These organisms will as a rule be found to be resistant to penicillin The combination of Chloromycetin® and erythromycin in doses recommended for acute infection will give adequate protection in most cases Antibiotics should be continued for some time

—usually for 2 weeks after wound revi sion Discontinuation of these agents too soon may result in an acute exacerbation due to multiplication of residual organ isms

Locally applied antibiotic solutions may be of some value in reducing suppuration However antibiotics so administered can *not come into intimate contact with bac* teria hidden in the deep recesses of wounds Accordingly full reliance is not placed on locally applied antibiotics in the absence of simultaneous parenteral admin istration The composition of antibiotic solutions used locally varies with the nature and sensitivity of the infecting organisms Among the more frequently used solutions are bacitracin 500 units/cc. in staphylococcal infections polymyxin B 500 units/cc. for B pyocyaneus streptomycin 25 000 units/cc for sensitive gram negative bacilli and penicillin 1 000 units/cc for gram-positive cocci Broad-spectrum anti biotics should be avoided because they are irritating to tissue and will increase exu date when locally applied

SPECIAL TYPES OF INFECTION —A vari ety of special types of infection may occur such as the burrowing ulceration due to micro-aerophilic hemolytic streptococcal infection or the synergistic gangrene due to the micro-aerophilic nonhemolytic streptococcus and Staph aureus These infec tions can be brought under control with the use of penicillin

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34 

Injuries to Major Tendons*

ANATOMY

A TENDON IS A strong arrangement of fibrous tissue in which the fibers of a muscle end and which serves as a bridge for attaching the muscle to a bone or other structure Tendons vary in size from that of the quadriceps muscle to the diameter of the extensor digiti minimi of the fifth finger of the hand. They have little if any elasticity and they are nourished by an inefficient blood supply Nerves supplying tendons end in what is known as "neurotendinous spindles" Tendons vary in length from a maximum of approximately 8 inches in the case of the plantaris tendon to only a few millimeters

MECHANISM OF INJURY

Tendons may be injured by one of three methods by a direct blow sustained by a blunt object which may severely bruise or lacerate the tendon by a sharp instrument which divides the skin and tendon underneath or by an indirect pull such as that sustained by the Achilles tendon when the calf muscles are suddenly contracted with the foot fixed to the floor The more frequent type of injury is that sustained by a sudden indirect muscle contraction which pulls the tendon apart.

PATHOLOGICAL PROCESS

The tendon may rupture at one of three points at its musculotendinous junction in the central portion of the tendon or at its bony attachment (Fig 547) When the separation occurs at the musculotendinous junction or in the central portion of the tendon the result is a fraying-out of the tendon If the tendon ruptures from its bony attachment the rupture is likely to be more of a transverse tear and there is less fraying-out of the tendon fibers

SYMPTOMS AND SIGNS

The sudden rupture of the tendon by an indirect means may be accompanied by a loud snap as in the case of the plantaris tendon and the first symptom is that of weakness Pain in the injured part however is not a consistent symptom but there will be inability to flex or extend the

[Although injuries to major tendons are discussed elsewhere in this volume with particular reference to various individual joints it seems worth while to include a separate chapter on the general subject of trauma to major tendons.—ED.]

part unless accessory muscles can be brought into play In the case of Achilles tendon ruptures plantar flexion of the foot can very often be carried out by the intact flexors of the toes and the posterior tibial tendon but with a baseball finger where the extensor tendon is ruptured and no ac cessory muscle can be utilized there will be no ability to extend the distal phalanx of the finger

If the tendon is superficial an actual defect in its contour may be palpated as is frequently possible in Achilles tendon ruptures or when the quadriceps is separated from its patellar attachment Immediate weakness and pain are followed by a mod erate amount of swelling and perhaps by some discoloration.

TREATMENT

Except in rare instances most tendon injuries require surgical repair to restore function. Those which do not necessarily demand operative treatment are the ex tensor tendon of the finger (baseball fin ger) or the plantaris tendon, which is not essential for good function of the calf mus cle group However the Achilles tendon the quadriceps tendon the long head of the biceps the distal end of the biceps the patellar tendon the extensor of the thumb the flexor hallucis longus and the anterior tibial and posterior tibial tendons usually require surgical repair

The Achilles Tendon

In a recent review of tendon injuries treated at the Massachusetts General Hospital over a 50-year period injuries to Achilles tendon comprised one fifth of all the large-tendon injuries encountered During this period 31 patients were treated for injuries to the Achilles tendon and 23 were followed for a sufficient length of time to permit adequate evaluation of the type of treatment carried out. Five patients received delayed treatment and had surgical repair of the ruptured Achilles tendon from 2 to 14 months following injury The group followed up consisted of 4 women and 19 men and ranged in age from 17 to 71 years The injury was not bilateral in any of these cases

The predominant symptom was pain weakness in plantar flexion was the most

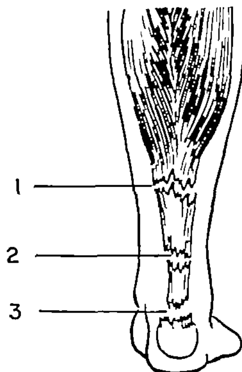


Fig 547 —Common sites of tear of Achilles tendon 1 at musculotendinous junction 2 in the central portion of tendon 3 at its bony attachment. (From Lawrence G H Cave E F and O Connor H Injury to the Achilles tendon—experience at the Massachusetts General Hospital 1900–1954 Am J Surg 89 795 1955)

common sign On examination a palpable gap in the continuity of the tendon was present in all patients

The dehiscence of the tendon was complete in 16 cases with the plantaris tendon remaining intact in 6 of these complete ruptures The separation occurred at the musculotendinous junction in 8 cases in the tendon itself in 14 cases and at its insertion into the os calcis in 1 case The findings at operation were usually those of hemorrhage and a markedly frayed tendon.

Suturing was done in all patients in this series (Fig 548) following exposure of the tendon and with one exception all patients were immobilized for a period of 3–4

weeks in toe-to-groin plaster to hold the knee in flexion and the foot in slight equinus position After a variable period of protected weight bearing all the patients were able to return to work or resume previous activity in 3–5 months and walk with no limp and with normal ankle joint motion is followed by 4–6 weeks of plaster immobilization a good result can be expected.

The Quadriceps Tendon

A rupture of the quadriceps tendon occurs at its bony attachment to the patella

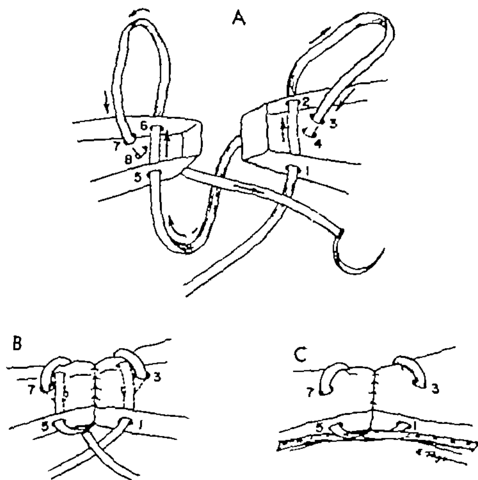


Fig 548 —Diagrammatic sketches showing technique of approximating divided Achilles tendon A placing of the suture The 2 ends of the tendon are mobilized and brought up into the wound A mattress suture of fascia ⅛ of an inch wide × 8 inches long (taken with a fascial stripper) is used to approximate the separated tendon B approximating the divided tendon and tightening the fascial strip A reinforcing layer of silk sutures the tendon edges C suture of ends of fascial strip to side of tendon (From Lawrence G H Cave E F and O'Connor H Injury to the Achilles tendon—experience at the Massachusetts General Hospital 1900–1954 Am J Surg. 89 795 1955)

Following operation all 23 patients obtained good functional results All were able to stand on tiptoe on the injured side and had forcible plantar flexion and dorsiflexion of the foot through a full range of motion It may be concluded therefore that regardless of the method of suture if repair of the tendon is carefully done and

Characteristically such a rupture occurs in middle-aged or older adults and is practically always sustained by a sudden contracture of the quadriceps muscle as the knee is flexed from 30 to 60 degrees thereby pulling the quadriceps tendon from its patellar attachment. The tear is usually complete Immediate pain and inability to

extend the knee against gravity are signs of this injury Palpation will reveal a defect between the patella and the quadriceps tendon Complete laceration of the tendon from its bony attachment frequently occurs and surgical repair is always required

X ray films of the knee joint should be made to determine whether there is a fracture of the patella or a simple separation of the quadriceps tendon from its bony attachment.

Operation should be carried out as soon as possible A parapatellar incision a straight longitudinal incision or a transverse incision may be used A transverse incision which adequately exposes the point of injury is preferred. The blood clot is removed from between the patella and the torn quadriceps the knee joint is exposed in order to remove cartilaginous or bony fragments Repair is carried out by using silk to suture the lateral expansions and fascia is employed as a mattress suture through the tendon and through drill holes in the patella (Fig 549)

Postoperative immobilization in a plaster cylinder is utilized until the wound is healed Quadriceps-setting exercises are started on the first day after operation and are continued for an indefinite period of time As soon as the wound is satisfactorily healed gentle active flexion of the knee is encouraged The patient is kept in bed until he can lift his leg against gravity with the knee fully extended and until he has from 70 to 90 degrees of active flexion of the knee joint Such restoration of flexion

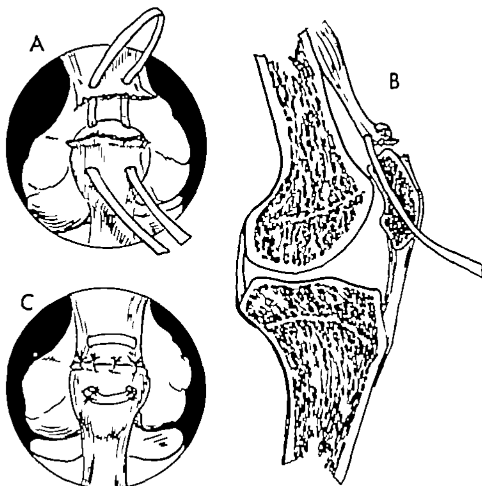


Fig 549 —Repair of quadriceps tendon by fascial strip removed from same thigh A, placing mattress suture of fascia. B horizontal view of same C approximation of tendon to patella by tightening fascial strip A reinforcing layer of silk suture is added

indicates flexibility of the quadriceps muscle This places less strain on the line of suture as flexion of the knee is carried out Careful instruction in crutch walking is essential Full weight may be borne but precaution must be taken to avoid sudden flexion of the knee The patient must guard against catching the heel or toes of the foot as he walks with crutches Crutches are continued for a period of 5–6 weeks During this period of time an essentially normal motion of the knee is restored

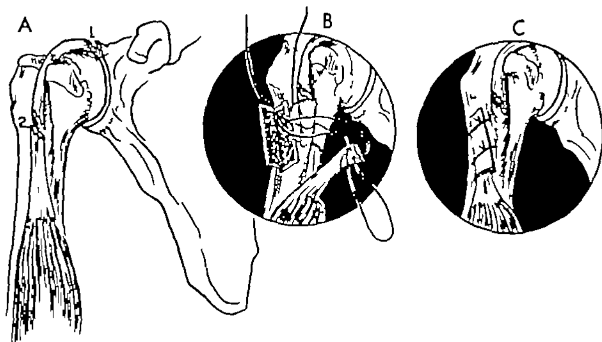


Fig 550 —Repair of rupture of long head of biceps tendon A, rupture possible at glenoid attachment (*1*) or at level of surgical neck of humerus (2) Suture at the glenoid is usually *not possible Consequently the distal fragment is sutured to the upper end of the humeral shaft* under a flap of bone (B and C) (See text.)

The Long Head of the Biceps Tendon

Rupture of the long head of the biceps tendon is usually produced by a sudden lifting motion with the elbow flexed There may be only slight pain and disability at the onset and frequently such an injury goes unrecognized until a few days after the injury when there is noticeable bulging of the biceps muscle belly This calls the patient s attention to the disability and frequently he seeks medical advice too late *to effect* adequate attachment of the biceps tendon Usually this injury causes so little disability that the patient is reluctant to have surgical repair carried out.

However if he is seen within a matter of days it is possible to expose the long head of the biceps tendon and suture it to the upper shaft of the humerus The tear generally occurs at the glenoid attachment or at the level of the surgical neck of the humerus and repositioning of the tendon is usually not possible The ruptured tendon is exposed through the deltopectoral approach reflecting the deltoid from its attachment to the clavicle The interval between *the deltoid and the pectoralis major* muscles is located The cephalic vein is retracted or ligated and the deltoid muscle is retracted laterally The ruptured tendon *is usually found lying anterior to the* subscapularis tendon but occasionally it may be necessary to detach the upper portion of the pectoralis major insertion into the *humerus in order to locate the* end of the ruptured tendon The tendon is then pulled upward and sutured to the upper shaft of the humerus (Fig 550) Braided silk is passed *through* the tendon into two drill holes in the upper humeral shaft firmly re-

attaching the tendon Postoperatively the arm is immobilized for a period of 3–4 weeks in a light hanging cast with the elbow at 90 degrees which allows use of the hand At the end of this period of im mobilization gentle active flexion and ex tension of the elbow is encouraged until a full range of elbow motion is obtained The patient should be cautioned to avoid sud den forceful contracture of the biceps muscle and also to avoid lifting heavy objects for a period of 6 weeks following tendon palpation in the anterior aspect of the arm may reveal a defect between the muscle and the upper end of the radius

Surgical repair (Fig 551) should be carried out as soon as possible after injury and before contracture of the biceps mus cle shortens the tendon If operation is done within a few days the tendon can be reattached to the radius by placing a drill hole through the upper end of the radius and suturing the tendon to bone with silk. If operation is delayed fascia lata repair

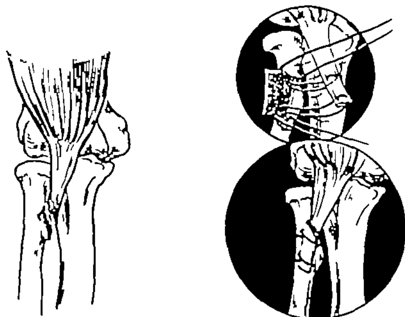


Fig 551 —Repair of rupture of distal biceps tendon Although rarely separated this tendon can usually be sutured to its radial attachment if the elbow is flexed The tendon is sutured to bone under a flap of bone and periosteum at the level of the bicipital tubercle

repair so that the tendon may become firmly reattached

The Distal Biceps Tendon

Rupture of the distal biceps tendon from its radial attachment is rare It is sustained by lifting a heavy object with the elbow flexed With a sudden contracture of the biceps muscle the tendon is pulled from its attachment to the biceps tubercle at the upper end of the radius Usually there is immediate pain and some limitation of motion of the elbow However flexion of the elbow can frequently be carried out by the supinator muscle which acts as a substi tute There is immediate swelling Careful of the tendon may be used to bridge the gap between the contracted tendon and the biceps tubercle of the radius After opera tion the elbow should be kept in a flexed position of about 90 degrees for a period of 4 weeks at which time active use of the elbow should be encouraged If repair is carried out early a good functional result should be obtained

The Extensor Tendon of the Thumb

Characteristically rupture of the exten sor pollicis longus tendon occurs at the level of the radial styloid Vigorous at tempts at reduction of Colles fractures

with traction exerted on the thumb and the wrist in ulnar deviation will cause a rupture of this tendon (Fig 552) The ten don is stretched over the broken fragments of the radius producing a laceration at this level.

Many instances of late rupture of this tendon are reported in the literature The rupture occurs after prolonged wear and tear on the tendon as it moves to and fro over the roughened or ragged dorsal sur face of the fractured radius Pain at the site of rupture and inability to fully extend the distal phalanx of the thumb are the usual signs of this injury

Surgical repair is immediately indicated. The tendon is approached through a longi tudinal incision beginning at the wrist joint and extending proximally along the dorsum of the radius to the junction of the middle and lower third of this bone If contracture of the extensor pollicis longus muscle has taken place so as to prevent primary suture of the proximal end to the distal end then a tendon transfer pro cedure which will restore functional exten sion to the distal phalanx of the thumb is indicated A free-tendon graft using the palmaris longus tendon may be utilized to bridge the gap between the severed tendon

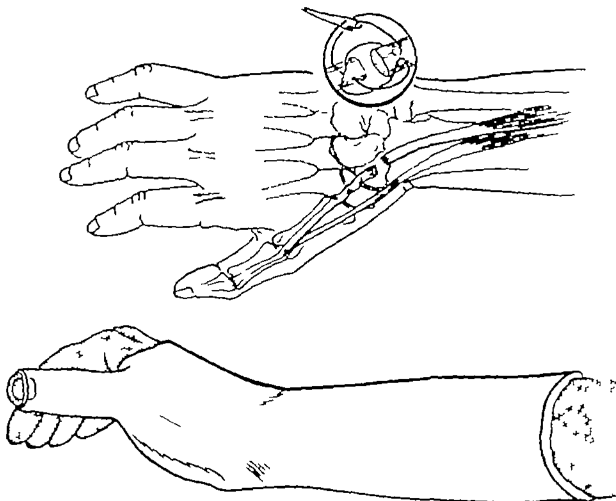


Fig 552.—Repair of extensor pollicis longus tendon Occasionally this tendon is separated in Colles fracture or it may be pulled apart by manipulation of the fracture The tear is usu ally at the level of the radial styloid Direct suture of the tendon is indicated as soon as pos sible to prevent contracture of the proximal portion If it is not possible to suture the tendon under the transverse carpal ligament the subcutaneous positioning of the sutured tendon will suffice or the distal end of divided tendon may be sutured to extensor indicis proprius tendon (see text) **Top** site of rupture of tendon **Bottom** plaster immobilization after tendon repair

ends However a more satisfactory procedure is to use the extensor indicis proprius tendon which is divided just distal to the dorsal carpal ligament and is relocated through the tunnel of the extensor pollicis longus tendon and sutured to the distal fragment of this tendon The pull-out wire technique is recommended as the method of suture when approximating the severed tendon ends and also when a tendon transfer procedure is performed (see Chapter 23 on Hand Injuries) Postoperatively the extremity is immobilized in plaster for 3 weeks maintaining the thumb in its functionally opposed position with the distal phalanx in maximum extension The wrist joint is held in approximately 15 degrees of extension At the end of 3 weeks the plaster is removed for brief periods during the day and the patient is given exercises to restore flexibility to the wrist joint and the thumb Caution must be exercised for an additional 3 weeks to avoid sudden full flexion and opposition of the thumb and palmar flexion of the wrist joint otherwise too much tension may be placed on the suture line in the tendon causing it to break. An adequate temporary plaster splint for the thumb and wrist is used during this 3-week period Six weeks after tendon suture the patient may begin to regain full function of both the wrist and thumb

Direct trauma with a blunt or sharp instrument may divide this tendon If the wound is dirty or if there is a delay greater than 4–6 hours between the time of injury and the time repair is contemplated debridement and primary suture of the skin laceration should be performed Repair of the tendon should be postponed until the laceration has completely healed and the danger of wound infection has passed

The Extensor Tendon of the Finger (Baseball Finger)

Rupture of the extensor tendon of the finger is a very common injury and usually results from a direct blow on the distal end of the extended finger Such an injury produces a transverse separation of the extensor tendon from the dorsum of the distal phalanx of the finger As a rule the lateral expansions of the tendon remain intact Therefore if prompt application of a splint with the distal interphalangeal joint in hyperextension and the proximal interphalangeal joint in 30 degrees of flexion is carried out good restoration of function and ability to hyperextend the finger will be restored The splint should be worn for a period of 6 weeks Even if treatment is delayed complete restoration of function is possible by the use of a splint for at least 6 weeks Some authorities believe that surgical repair should be carried out but this has not been found advisable at the Fracture Clinic of the Massachusetts General Hospital

Not infrequently such an injury will be accompanied by a pulling-off of a fragment of the dorsum of the proximal portion of the phalanx If the fracture is old surgery is performed (Fig 553) removing the bone fragment and suturing the tendon to the phalanx with fine silk. Postoperatively the finger must be immobilized in a splint which holds the distal interphalangeal joint in hyperextension and the proximal interphalangeal joint in 30 degrees of flexion for a period of at least 6 weeks At the end of 6 weeks exercises to restore full function to the finger are encouraged

The Patellar Tendon

Rupture of the patellar tendon is rare It is not infrequent in Paget s disease of the tibia, when the tendon actually separates from its bony attachment at the tibial tubercle Symptoms are comparable to those experienced when the quadriceps is lacerated and there is inability to extend the knee X ray films of the knee in this type of injury may reveal actual separation of a portion of the tibial tubercle which if in good position may reattach itself if the leg is immobilized in plaster with the knee in complete extension for a period of 6–8 weeks If there is wide separation of the fragment or if the injury is confined to

with traction exerted on the thumb and the wrist in ulnar deviation will cause a rupture of this tendon (Fig 552) The ten don is stretched over the broken fragments of the radius producing a laceration at this level.

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Surgical repair is immediately indicated. The tendon is approached through a longitudinal incision beginning at the wrist joint and extending proximally along the dorsum of the radius to the junction of the middle and lower third of this bone If contracture of the extensor pollicis longus muscle has taken place so as to prevent primary suture of the proximal end to the distal end then a tendon transfer procedure which will restore functional extension to the distal phalanx of the thumb is indicated. A free-tendon graft using the palmaris longus tendon may be utilized to bridge the gap between the severed tendon

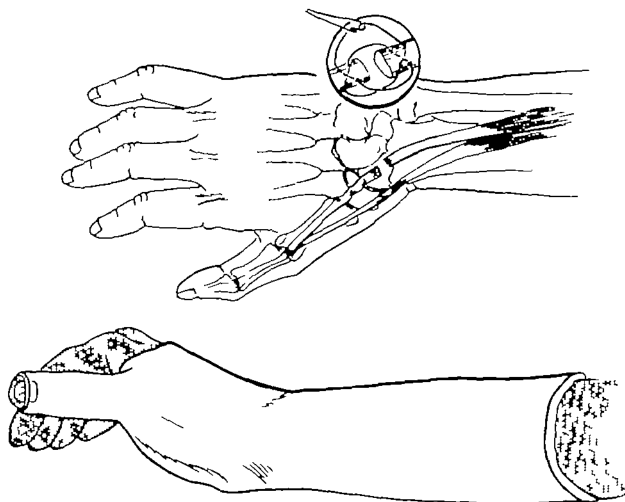


Fig 552.—Repair of extensor pollicis longus tendon Occasionally this tendon is separated in Colles fracture or it may be pulled apart by manipulation of the fracture The tear is usually at the level of the radial styloid Direct suture of the tendon is indicated as soon as possible to prevent contracture of the proximal portion. If it is not possible to suture the tendon under the transverse carpal ligament the subcutaneous positioning of the sutured tendon will suffice or the distal end of divided tendon may be sutured to extensor indicis proprius tendon (see text) Top site of rupture of tendon. Bottom plaster immobilization after tendon repair

ends. However a more satisfactory procedure is to use the extensor indicis proprius tendon, which is divided just distal to the dorsal carpal ligament and is relocated through the tunnel of the extensor pollicis longus tendon and sutured to the distal fragment of this tendon The pull-out wire technique is recommended as the method of suture when approximating the severed tendon ends and also when a tendon transfer procedure is performed (see Chapter 23 on Hand Injuries) Postoperatively the extremity is immobilized in plaster for 3 weeks maintaining the thumb in its functionally opposed position with the distal phalanx in maximum extension The wrist joint is held in approximately 15 degrees of extension At the end of 3 weeks the plaster is removed for brief periods during the day and the patient is given exercises to restore flexibility to the wrist joint and the thumb Caution must be exercised for an additional 3 weeks to avoid sudden full flexion and opposition of the thumb and palmar flexion of the wrist joint otherwise too much tension may be placed on the suture line in the tendon causing it to break. An adequate temporary plaster splint for the thumb and wrist is used during this 3-week period Six weeks after tendon suture the patient may begin to regain full function of both the wrist and thumb

Direct trauma with a blunt or sharp instrument may divide this tendon If the wound is dirty or if there is a delay greater than 4–6 hours between the time of injury and the time repair is contemplated debridement and primary suture of the skin laceration should be performed. Repair of the tendon should be postponed until the laceration has completely healed and the danger of wound infection has passed

The Extensor Tendon of the Finger (Baseball Finger)

Rupture of the extensor tendon of the finger is a very common injury and usually results from a direct blow on the distal end of the extended finger Such an injury produces a transverse separation of the extensor tendon from the dorsum of the distal phalanx of the finger As a rule the lateral expansions of the tendon remain intact Therefore if prompt application of a splint with the distal interphalangeal joint in hyperextension and the proximal interphalangeal joint in 30 degrees of flexion is carried out good restoration of function and ability to hyperextend the finger will be restored The splint should be worn for a period of 6 weeks Even if treatment is delayed complete restoration of function is possible by the use of a splint for at least 6 weeks Some authorities believe that surgical repair should be carried out but this has not been found advisable at the Fracture Clinic of the Massachusetts General Hospital

Not infrequently such an injury will be accompanied by a pulling-off of a fragment of the dorsum of the proximal portion of the phalanx. If the fracture is old surgery is performed (Fig 553) removing the bone fragment and suturing the tendon to the phalanx with fine silk Postoperatively the finger must be immobilized in a splint which holds the distal interphalangeal joint in hyperextension and the proximal interphalangeal joint in 30 degrees of flexion for a period of at least 6 weeks At the end of 6 weeks exercises to restore full function to the finger are encouraged

The Patellar Tendon

Rupture of the patellar tendon is rare It is not infrequent in Paget s disease of the tibia, when the tendon actually separates from its bony attachment at the tibial tubercle Symptoms are comparable to those experienced when the quadriceps is lacerated and there is inability to extend the knee X ray films of the knee in this type of injury may reveal actual separation of a portion of the tibial tubercle which if in good position may reattach itself if the leg is immobilized in plaster with the knee in complete extension for a period of 6–8 weeks If there is wide separation of the fragment or if the injury is confined to

the tendon attachment surgical repair is indicated Direct exposure of the tendon and suture to the tibial tubercle with heavy silk will effect a good result provided that plaster immobilization following repair of the tendon is carried out for a period of 6 weeks If the tendon ruptures through its midportion or at its inferior patellar attachment surgical repair is indicated by use of silk or fascial sutures

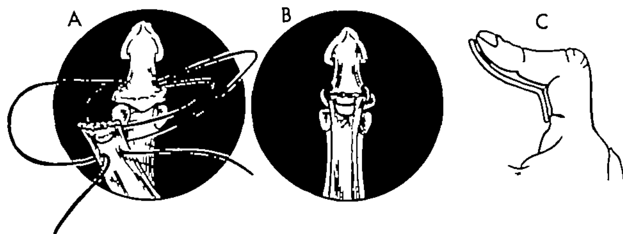


Fig 553 —Repair (as sometimes indicated) in old case of separation of extensor tendon from distal phalanx. A mattress suture of fine silk or wire is passed through the tendon (A) One end of the suture is first passed through a small drill hole in the base of the phalanx from right to left while the other end of the suture is passed through from left to right The two ends are brought back through the tendon and tied (B) A postoperative splint is worn for about 6 weeks (C)

The Anterior and Posterior Tibial Tendons

Division of the anterior and posterior tibial tendons is rarely due to a sudden contracture of the muscles it is more frequently caused by a direct blow or laceration Unfortunately the injury frequently goes unrecognized because functions of these two tendons can be taken over by associated muscles

Spontaneous rupture of the posterior tibial tendon is an exceptionally rare injury Only 1 case of a spontaneous partial rupture of the posterior tibial tendon is reported in the literature This occurred in a 65-year-old steamfitter who slipped while carrying lead pipes downstairs and jumped down four steps landing on his foot and twisting the ankle Pain and swelling over the medial aspect of the ankle were not noted until 10 days after the injury and this disability persisted until 6 months after injury when the posterior tibial tendon was explored and found to be partially lacerated After repair of the tendon the patient returned to work, with only occasional discomfort in the region of the ankle joint.

A similar injury was recently repaired in the Fracture Clinic of the Massachusetts General Hospital The patient, a 57 year old woman complained of recurrent ankle sprains and for 3 months had increasing pain and swelling over the posteromesial aspect of the left ankle The preoperative diagnosis was "ganglion" or possibly "synovioma " At operation a complete laceration and fraying-out of the posterior tibial tendon was found at the level of the internal malleolus (Fig 554) Repair was carried out by bringing the two frayed ends together and suturing them with silk. A plaster boot was worn for 6 weeks

The following are illustrative cases of traumatic lacerations of the posterior tibial tendon and the anterior tibial tendon

A 10-year-old boy sustained a laceration over the medial malleolar region of the left

ankle while swinging an ax The skin laceration was sutured Eighteen months after his injury he complained that he did not walk properly and that the left foot was more pronated than the right Examination



Fig 354 —Top complete rupture of posterior tibial tendon at level of left ankle a rare injury 1 proximal end of tendon 2 internal malleolus 3 distal end of tendon. Bottom tendon repair Two ends of tendon are brought together and sutured with silk Plaster immobilization is used for 6 weeks At end of 5 months patient was symptom-free tendon function was normal.

disclosed that there was a well healed scar just behind the medial malleolus and that the posterior tibial tendon was not functioning

The posterior tibial tendon was explored and found to be completely divided there was a 3-inch gap between the divided ends Repair of the tendon was carried out by using as a graft a third of the Achilles tendon 4 inches long This was sutured to the proximal stump of the tendon and passed through a drill hole in the tarsal navicular bone The tendon graft was then sutured to the distal stump of the posterior tibial tendon

Following operation the leg was immobilized in a toe to-groin plaster for 6 weeks with the foot in inversion and dorsiflexion and the knee flexed at 45 degrees Good function of the posterior tibial tendon was restored

A 15-year-old schoolboy sustained a laceration over the anterior tibial tendon just above the ankle while chopping wood The skin wound was sutured on the day of the injury but the anterior tibial tendon was not inspected Four days following repair of the laceration the boy noticed that he could only weakly dorsiflex and invert the foot Examination showed that the an terior tibial tendon was not functioning and that he could not walk on the heel of the foot

The anterior tibial tendon was explored through an incision incorporating the old scar and was found to be divided across half of its diameter A repair of the tendon was carried out using silk sutures and the boy was placed in a short leg plaster casing with the foot in inversion and dorsiflexion The plaster was removed 6 weeks after ten don repair Seven months following repair of the lacerated tendon the boy was en gaged in normal activities The tendon was functioning normally

The surgeon must carefully consider the possibility of a divided anterior or posterior tibial tendon if there has been a laceration around the ankle on the anterior or pos teromedial aspect. When such an injury is suspected the tendon should be explored before the subcutaneous tissue and skin are sutured Prolonged disability may be prevented and earlier complete function restored to the lower extremity by immediate tendon repair

The Flexor Hallucis Longus Tendon

Separation of the flexor hallucis longus tendon from the distal phalanx of the great toe is rare only 1 case has been seen at the Fracture Clinic of the Massachusetts General Hospital. This injury occurred to a boy who was running upstairs and whose weight was suddenly borne fully upon the distal portion of the great toe The tendon was separated from its bony attachment. In such a case surgical repair is indicated.

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35 Soft-Tissue Repairs

SOFT TISSUE INJURY IS to a greater or lesser degree the inevitable accompaniment of a fracture In most fractures the amount of soft tissue injury is fortunately not so severe or extensive that the final result is jeopardized But the surgeon treating a fracture should be prepared to choose an appropriate method of dealing with soft tissues and to use the method effectively in the face of any difficulties The concept that deep healing can be no better than the surface closure is perhaps nowhere better exemplified than in the management of trauma.

Difficulties of wound closure arise not only in severe open injuries with obvious soft-tissue loss they may also complicate open reduction of a closed fracture (Fig 555) or the ill advised use of a plaster casing or splint. Restoration of the skin covering at the time of reduction and fixation of the fracture is desirable to prevent further external contamination to reduce the hazards of infection and to minimize fibrosis and interference with local blood supply Thus wound closure is an essential part of the definitive treatment of any fracture which is operated upon cannot be disregarded for considerations of exposure of the fracture site or anatomical reduction of the bone But closure must be carried out with thoughtful concern for skin circulation, avoiding tension in the suture line and resorting to delayed primary closure or other methods if immediate suture is hazardous or impossible

In any active fracture service there will be wounds which break open because of deep infection or failure of the suture line to heal there will be areas of ischemic necrosis of the skin there will be avulsion or losses of skin arising from the trauma itself and there will be deep wounds associated with fractures The purpose of this chapter is to recount some of the soft tissue complications that have been observed and to call attention to possible ways in which these complications can be treated

Skin, the barrier between external and internal milieus and thus the key to every wound closure is nourished by a plexus of blood vessels which course immediately beneath the dermis sending branches into the skin papillae These in turn are supplied by larger vessels in the subcutaneous fat superficial to the deep fascia The pattern of the deeper vascular channels is governed by the even larger vessels lying deep to the fascial layer Thus the blood supply of the skin over the perforating branches of the internal mammary vessels, or along the course of the thoracoepigastric vessels or around the knee where the multiple geniculate branches are given off by the popliteal artery follows an established pat

tern These patterns are useful in the planning of repairs

The arrangement of vessels in the skin and in most other areas of the body with the exception of the long axis of an extremity does not follow a linear course Vascular anastamoses across the midline of the trunk are said to be fewer than in the adjacent subcutaneous tissues And the skin of the lower leg especially the anterior surface where there is minimal subcutaneous tissue is notoriously susceptible to ischemia and necrosis When trauma is encountered or repairs contemplated in these areas of random circulation special attention must be given to judging the condition of the skin Care must be exercised in the manipulation of the skin to avoid closure under tension and to avoid marginal necrosis by constricting sutures

METHODS OF WOUND CLOSURE

The surgeon has the choice of four methods of wound closure linear closure closure with a free-skin graft closure with a local flap or closure with a remote flap. Familiarity with the advantages and disadvantages and the indications and limitations of each method will simplify the selection of the most suitable one



Fig. 555 —A closed comminuted spiral fracture of the tibia treated by open reduction and plating When the wound broke open there was considerable necrosis of skin, sequestration of much of the anterior tibia, and serious infection in the local tissues (A) The granulating areas surrounding the exposed bone were closed promptly by skin grafts and after the sequestra were removed the viable bone was also covered with skin grafts With the elimination of infection by wound closure bone union progressed to a solid but weak bone bridge in the tibia (B) A direct flap (C) from the opposite thigh was used to replace the skin grafts and provide a well-vascularized and flexible cover of normal skin over the damaged tibia. Finally the tibia was strengthened by a bone graft inserted beneath the flap (D)

LINEAR CLOSURE

The normal method of wound closure is by approximation of the edges The wound may be an incised wound in which the edges are smooth and undamaged or it may be an open wound with ragged crushed edges that must be excised before closure can be safely carried out Suture

must be without undue tension and with carefully placed stitches The edema of the tissues at the fracture site may be great enough to prevent closure without tension despite the absence of skin loss The so-called "fracture blister" is merely an evi dence of the impaired circulation associ ated with acute edema Compromise of the local blood supply by tight sutures may result in necrosis at the margins where the sutures are constricting or it may pro duce enough regional ischemia to cause wider destruction of skin Exposure of sub-cutaneous tissues or the bone serious in fection in the devitalized tissues and long delays in healing of all tissues will result Blanching of the skin an evidence that blood is being expressed from the tiny ves sels of the skin is the best warning of im paired circulation Delayed primary clo-sure so well demonstrated in World War II and used routinely in some fracture services today as a method of dealing with open injuries should always be kept in mind in fractures of the distal extremities (lower leg and forearm) in which the amount of skin envelope is limited Swell ing of the deeper tissues is more likely to produce wound complications in these areas because of the limited skin envelope

Because the nutrient blood vessels of the skin lie in the *papillae and course im* mediately beneath the dermis wide sutures which can interfere with the skin circula tion should be avoided Skin approximation can perhaps best be secured by sutures buried in the fatty subcutaneous tissue and by subcuticular stitches of fine suture ma terial. Loose closure of the deep inelastic fascia will suffice with adequate skin cover ing. If direct closure cannot be carried out some alternative method such as a free skin graft or a local flap must be used

Closure by Skin Transplantation

Skin may be transplanted in two ways (1) free transplantation or skin grafting which means that the skin is completely detached from the body in its transfer and (2) transplantation as a flap which means that at all times the skin and sub-cutaneous tissues remain attached to the body and receive blood supply through this attachment or pedicle The free-skin graft must be thin without any subcutaneous tissue to survive and grow after transfer whereas the flap must retain the subcuta neous tissues in which the nutrient vessels lie

Skin Grafting

The free split skin graft is one of the most useful techniques available to the sur geon dealing with trauma. Unfortunately it is too frequently overlooked There are few traumatic wounds with skin loss that cannot be closed by a skin graft either on a raw surface of subcutaneous tissue or on muscle or even on cancellous bone In most acute wounds the direct application of a skin graft is possible Only if hemo-stasis is a problem is there reason to post pone the application of a graft and in that situation the graft should certainly be applied before 4–5 days have passed Whether the skin graft will provide the de-finitive covering or not is immaterial. Its immediate function is to convert the open wound into a closed one so that deep heal ing can progress Final evaluation of the stability of the skin graft can be made at a later date

A properly prepared clean granulating wound following failure of primary wound closure infection or ischemic necrosis of skin can be closed by a skin graft. Both the general condition of the patient and the local condition of the wound will im prove as the total area of raw surface is reduced Even the granulating wound sur rounding exposed or necrotic soft tissue or bone should be closed early with a graft The drainage will diminish promptly the care of the wound is made easier and the necrotic tissue will sequester with less re-action. Not infrequently apparently devi talized bone will begin to show evidence of recovery by the development of granula

tions on its surface and by spontaneous epithelial spread from the surrounding grafted skin (Fig 556)

SECURING THE SKIN GRAFT —The split skin graft as the name implies is cut at approximately the midthickness of the der mis. The cut is considerably deeper than the rete pegs and germinal layer which From the transected openings of these structures pour out the cells that re-establish the epidermal layer The term dedif ferentiate" has been used to define the reversion of the function of the cells lining these special structures to the more simple squamous epithelial form. Spontaneous healing of the donor site which is usually



Fig 556 —Examples of granulating bone defects closed with skin grafts Localized osteomyelitis was controlled by wound closure. Left necrosis and infection of head of humerus following open reduction which required removal of the head After the deep concavity was lined with the skin grafts infection in the bone subsided and the remaining raw surface healed spontaneously Repair with a flap was contemplated later Right infection of tibial shaft following intramedullary nailing Decortication of the bone was necessary for adequate drainage, after which both upper and lower cavities were lined successfully with skin grafts Photograph shows condition of upper cavity at time of skin grafting and healed distal cavity

form the base of the normal epidermis Skin grafts thus consist of the normal epi dermis and variable thicknesses of the dermal layer determined by the depth of the cut. The only epithelial elements that remain are the roots of the hair follicles and the sebaceous and sweat glands which lie in the depths of the dermis These specialized structures are the normal developmental offshoots of the epidermal layer complete in 12–14 days is marked by the restoration of an intact impervious outer layer of the skin

The graft may be cut by a razor by a special thin bladed knife or by one of sev eral machines termed "dermatomes." It is desirable in any wound with impaired blood supply or with chronic low grade sepsis to secure a thin sheet of skin because a thinner sheet of skin is more likely to sur

vive To survive it must be transplanted either to a freshly prepared raw surface or to a granulating surface free of active in fection At first the graft is nourished by osmotic interchange with the underlying tissues but within 2–3 days there is abun dant evidence of active circulation and re vascularization of the skin If nutrition of the skin graft is inadequate because of an unhealthy local wound or general malnu trition of the patient the graft may be overwhelmed by sepsis or autolysis and fail to survive

Elasticity texture and toughness of the skin, and anchorage and stability to the epidermis is provided by the dermis The dermis does not regenerate When destroyed, it is replaced by scar tissue which lacks the elastic fibers and consequently the resiliency that characterizes the der mis Spontaneous epithelial spread across a granulating surface will provide a protec tive layer of "scar epithelium" but this thin sheet may be unstable and ulcerate repeatedly without the anchorage and me chanical support of the underlying dermis Epidermoid cancer may develop in such scars if they are allowed to become the site of recurrent or chronic ulceration or irri tation.

Transfer of a Flap

The flap method of transplanting skin as stated above differs from the free-skin graft since the flap is attached at all times to the body by a pedicle The flap consists of not only the full thickness of the skin but also the underlying subcuta neous fat in which the nutrient vessels of the skin lie It may be transplanted in two principal ways as a direct flap or as a delayed flap Transfer of a *direct flap* is possible when sufficient blood supply through the attachment or pedicle can be insured, either because recognized major blood vessels are present in the pedicle to provide adequate blood supply or because the attachment is sufficiently broad to contain enough vessels to insure the necessary blood supply The statement has been made that no flap should be more than twice as long as the width of its attach ment or pedicle If this rule is followed to the letter there will be instances of necrosis of the distal end of the flap because of inadequate blood supply It is preferable if possible that the direct flap be no more than half again as long as the width of the attachment This places limitations on the availability of direct flaps but it is usually feasible to use a direct flap from the trunk for any part of the upper extremity and most repairs of the lower extremity can be carried out with a direct flap from the opposite leg

By the *delayed transfer* of a flap is meant the gradual severing of the major blood vessels entering a flap on three sides leaving only the blood vessels at the base or pedicle of the flap intact when the flap is finally moved By this method longer and narrower flaps can be safely transferred to an adjacent local area or to a more remote part of the body It should be emphasized that the delay of a flap is a multiplestage procedure After the pattern of the flap has been outlined on the skin incisions are made on either side of the long axis of the flap These are carried down to the deep fascia. All the small subdermal vessels are severed, and the deeply lying vessels in the subcutaneous fat are interrupted by this cut At this primary procedure unless the flap is more than 3–4 times the length of its base or pedicle the flap is completely undermined, in order to interrupt the perforating vessels which emerge through openings in the deep fascia. The flap may then be left flat and su tured back in place after ligation of all active bleeding points or it may be formed into a rope or tube by suturing the skin edges of the flap together It is sometimes possible to close the adjacent skin beneath a tubed flap but more often a free-skin graft is necessary for closure Tubing a flap insures against any exposed raw surface during the multistage transfer of a flap from one area to another The disadvan tages of tubing are it may prove difficult to form a tube in a very obese person and

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there may be difficulties in adjusting the flap at the final step because of its rounded form

After the first step in the preparation of the flap is completed, major blood vessels at the distal end of the flap still remain. These must be severed before the final transfer can be safely accomplished The severance procedure requires the making of an incision across the end of the flap with the incision carried down to the deep fascia. It should not be necessary to undermine the flap further at this operation because the vessels on its undersurface should have been cut and tied at the initial procedure In a large flap or one with length greater than 3–4 times the width of its base or pedicle it may be desirable to carry out the delaying procedures in more than two steps Sometimes as many as four or five steps may be used in order to insure the blood supply and the viability of the sheet of skin and subcutaneous tissue

Occasionally small hematomas or areas of induration may occur in a flap during its preparation. Accumulations of blood should be evacuated and areas of induration watched until they have completely subsided. Transfer of a flap in the presence of local or diffuse induration localized infection or accumulations of blood is foolhardy and can result only in disastrous partial or complete tissue loss.

The use of a flap is indicated when the vascularity of the wound is insufficient for spontaneous healing of the damaged tissues—for example in nonunion of the tibia, which may heal spontaneously after the application of a blood bearing local flap to the injured area, or when there is need for a cushion between the skin and the underlying tissues such as over bony prominences or weight bearing areas A flap is also indicated when there is such deep scarring of a part that definitive primary or secondary surgery on bone tendon or nerve cannot be done successfully either because of insufficient soft tissue in which moving structures can glide or because the blood supply is inadequate to nourish the healing tissue in the operated area. *Finally the flap may be essential* to insure primary skin healing following reparative surgery



Fig 557 —*Left* ulceration over the lateral aspect of the knee with proved connections to the knee joint which was closed successfully after preliminary debridement and preparation of the wound. *Right* repair by local single-pedicled flap which rotated forward to cover the defect, *and by skin graft covering the donor area.*

Types of Flaps —A local skin flap may be taken from an adjacent untraumatized area and shifted into the defect left by the trauma (Fig. 557) It is unwise to use a local flap if the site from which the flap is to be secured is one that may be subject to trauma or weight bearing (Fig 558) Such areas include the skin overlying the malleoli or other bony prominences the weight-bearing areas of the sole of the foot

tibia often requires a retrograde flap in the opposite thigh Such a flap can usually be transferred without the need of a delaying procedure A flap from the medial aspect of the opposite calf is often the best source of skin for the sole of the foot. The calf may also be the source of covering for re pairs either in front or in back of the opposite knee

Defects of large areas of the lower ex



Fig 559 —Left unstable scar in center of the weight bearing portion of the heel Right the scar was excised and the defect repaired by a local single pedicled flap from the non weight bearing part of the arch The donor site of the flap was covered by a graft which is wrinkled but has good stability

tremity are the kind which require the greatest planning and skill, because remote flaps from the abdominal wall or elsewhere must often be transferred by means of an intermediate carrier such as the forearm or hand In preparing the original flap it is of the utmost importance to be sure that sufficient tissue is secured to insure com plete coverage of the damaged area.

CARE OF THE OPEN WOUND

There is no substitute for diligence in the care of the chronic open wound No topical or parenteral medication has yet replaced faithful mechanical cleansing, careful daily debridement and frequent changes of dressing The skin surrounding the wound as well as the wound itself must be kept scrupulously clean. Hair should be shaved off and all local epithelial debris washed vigorously away Exposed bone need not be trimmed away but any loose sequestra should be lifted from the wound. A single layer of fine gauze (44-mesh) moistened with saline solution to increase its capillarity and held firmly against the granulating surface has the advantage of minimal adherence to the wound itself without obstructing the wound drainage Bits of necrotic tissue will stick to the gauze and come away when the dressing is changed. Contact of the gauze with the whole wound surface is necessary In any concave wound or in one with a deep pocket the gauze should be packed loosely into the cavity to eliminate all "dead space" in which exudate may accu mulate and provide a local medium for infection The importance of preventing

accumulations of exudate in such cavities is far too often overlooked in the care of a wound

TECHNIQUES OF WOUND CLOSURE

Delayed Primary Closure

When primary closure is impossible and delayed primary closure must be resorted to the latter is best undertaken in about 5–7 days after injury The healing stimulus defined recently by a number of investi gators is then at its maximum Later the bacteria will have gained a foothold and the wound become an infected wound Also the adjacent soft tissue may have become so inflexible because of edema and fibrosis that tissue mobilization and closure will be impossible No attempt should be made to carry out a layer closure because the tissues will not accept a series of buried sutures. It is better to use loose stay sutures which will engage all layers of the wound collapse any dead spaces and per mit surface drainage through the gaps in the skin edges between the sutures

Skin Grafting

A wound that is unsatisfactory for closure within the limited period of time after injury or one that has opened spontane ously because of tension sepsis or necrosis of skin, is best converted from an open into a closed wound by a free-skin graft It should always be recognized that the sole function of the graft is to close the wound Healing of the deeper tissues (skin muscle etc) can then progress without the delays that accompany infection fibrosis and diminished blood supply If the location of a graft or the condition of the deeper tissues requires replacement of the graft with a flap it will still have served the important emergency function of protecting the wound

Cultures will be helpful in determining the bacterial flora in the wound and in selecting the antibiotics for treating invasive infection According to recent studies by Ye the pH of a wound provides another clue to its condition The more alkaline the pH (7 2 or above) the higher the per centage of successful skin grafts

The drilling of holes in the bony cortex devoid of periosteum or in eburnated bone at the fracture site in order to establish vascular connections between the marrow cavity and the overlying soft tissues is a useful adjunct to the attachment of a skin flap or preparation for the application of a free-skin graft There is nothing to be gained by drilling exposed necrotic bone which must be completely resected before the wound can be closed The vascular channels established between the marrow cavity and the outer surface of the cortex serve as anchorage for the soft tissue especially over eburnated bone from which the covering tissue can be easily dislodged.

The skin graft has a high resistance to infection but it must be nourished in its new site promptly before the destructive processes in the wound overwhelm it The condition of the wound the thickness of the graft and the temperature of the environment all contribute to success A thin graft is more likely to succeed on a wound of doubtful condition On the other hand a thicker split graft will shrink less and provide a smoother more stable surface Thin grafts cut with a dermatome are dif ficult to separate from the drum or the ad hesive strip and may tear when removed The thin graft can perhaps be best cut with a knife or its equivalent

It is seldom necessary or wise to suture a graft on a granulating surface especially on an extremity where effective "snubbing" of the graft in place with a circular band age is possible *Usually the graft will ad here promptly to a clean granulating sur face* probably by the interaction of plasma ingredients both on the undersurface of the graft and on the granulating surface A single sheet of skin is preferable to scraps of skin but wounds with many un even contours may require the fitting of several pieces of graft to the surface It is wise to trim the skin graft so that a margin (1 mm) of raw surface is left between the edge of the graft and the normal sur

rounding skin. If there is an overlap the graft may adhere to the skin and exudate which often appears at the junction will not migrate vertically to the surface but will be forced to spread beneath the graft and may destroy it A deep sinus from which drainage escapes is not a contra indication to grafting but the graft should be perforated above it in order to allow the escape of exudate Likewise holes in the graft should be made where bone or islands of epithelium are exposed, because the graft cannot grow on either

Immobilization of the graft and support with moderate compression by a protective dressing is desirable The dressing over a concavity in a deep pocket must be fitted accurately to the space in order to fulfill its function of holding the graft in place Likewise if the part is oval in shape as for the forearm and hand the dressing must be higher on the volar and dorsal surfaces than on the lateral surface in order to secure uniform compression

There is evidence that grafts may do better if maintained at normal skin temperature Occasionally therefore in areas where the problem of immobilization is slight or where the graft is glued firmly to the raw surface dressings may be omitted It is essential to check the wound daily in order to empty any accumulations of exudate beneath the graft and to remove the crusts that form at the graft margin. The exudate would of course normally be absorbed into the dressing if one were used but without a dressing the exudate dries and may act as a barrier to drainage A cradle may be desirable to prevent contact of the graft with the sheets which might dislodge it.

Postoperative Care of Grafts and Flaps

There is no hard and fast rule about the time for the first change of dressing of a skin graft Observation of the graft daily if no dressing is used will allow the most careful check of the progress of healing If a dressing is used daily inspection in the first few days after operation is dangerous because removal of the dressing may dislodge the graft If the dressing, serving the important function of immobilizing the graft must be removed and replaced the surgeon should weigh his ability to restore as good a dressing as that originally applied against the risks involved in postponing the removal of the dressing until the graft is more firmly healed in place

The following routines have generally been followed Grafts without dressings are observed daily Grafts on small granulating surfaces where a good dressing can be reapplied are examined on the third or fourth day Larger grafts or grafts applied at the donor site of a flap are examined between the fifth and seventh day

Dressings are applied to all flaps post operatively Moderate resilient compression (mechanic s waste) is maintained on the end of the flap with minimal compression on the pedicle The end of the flap is usually inspected within the first few hours after operation. Cyanosis of the skin is considered a serious prognostic sign because it means that venous return from the flap is inadequate This may result from kinking of the pedicle too great pressure on the pedicle or improper preparation of the flap When cyanosis is present the flap should be completely exposed the pedicle examined and efforts made to change the position so that the circulation will be improved If the congestion persists for more than 24 hours it is seldom possible to salvage the congested part of the flap

A complete change of the dressing on a flap is usually done by the fifth or sixth day and then repeated daily or on every second day thereafter In complex flaps from the trunk to the arm or from one leg to the other there may be small raw surfaces that could not be closed with a graft at the time the flap was transferred These are often not easily accessible and must be carefully watched and kept scrupulously clean Invasive infection from these surfaces can produce thromboses in the pedicle and loss of the flap

The pedicle of most flaps can be severed in 18–21 days after the graft. Earlier

separation of the pedicle is possible but there are risks involved in premature cutting of the pedicle which can be avoided by maintaining the attachment for a few additional days Several tests (histamine flare saline wheal fluorescein and others) can be used to judge the circulation in the end of a flap Any uncertainty about the condition of the circulation even after 3 weeks may make partial cutting of the pedicle desirable Final separation will be postponed until improved collateral circulation between the flap and the new bed has been established by interruption of the blood supply through the pedicle in two or more operations.



Fig. 560 —Open fracture of right tibia through which an open reduction was carried out (A) The wound broke down exposing the metal plate (*arrow*) Intensive daily local care and general antibiotics improved the condition of the wound sufficiently to permit direct closure A single-pedicled local flap was used because of the circular shape of the wound and because the condition of the lateral tissues was too uncertain to tolerate elevation of a double-pedicled flap (B and C) The bone plate was removed at the time of closure and a skin graft was used to close the donor area of the flap

Indications for and Use of Flaps

Complications from injuries on the lower leg have been the commonest cause of combined efforts by the fracture and the plastic services The leg is subject to direct trauma from the automobile bumper from heavy industrial materials from power equipment from logging operations and from other causes Over the anterior surface of the tibia the tibial tubercle and the malleoli there is a lack of the thick cushion of flexible soft tissue which overlies most other long bones Fractures of the leg are occasionally complicated by extensive avulsions or losses of soft tissue similar to those commonly seen in military casualties requiring prompt soft tissue replacement at the time of fracture reduction

The surgeon should always consider delaying the treatment of a closed fracture of the lower leg accompanied by extreme swelling and with or without blistering of the skin (an indication of locally impaired circulation) It is difficult however to postpone treatment of a displaced or open fracture Open reduction of the closed fracture before organization and resorption of the hematoma have begun is less complex because the parts are more easily identified and mobilized The hazard of operative

treatment of closed fractures is the risk of imperfect wound healing which can prolong recovery for years if wound disruption, *infection and bone necrosis develop* Perhaps the pendulum has swung too far in the direction of operative interference in closed fractures of the lower extremities

below the circular defect but the defect cannot be closed without tension and must therefore be closed immediately with a flap *of adjacent tissue* A single-pedicled flap, half again as large as the circular defect, can be raised from the lateral surface of the leg with the pedicle lying proximally

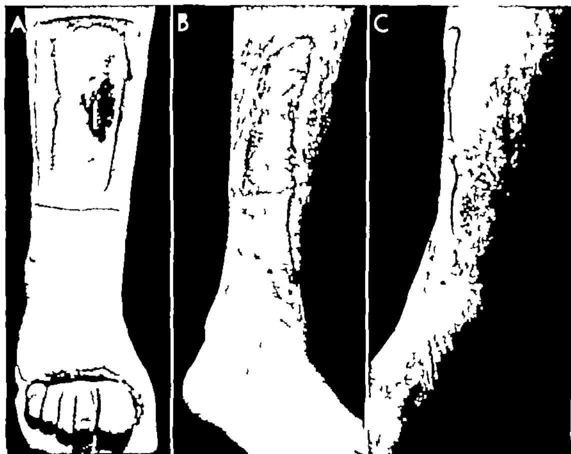


Fig 561 —Open fracture of tibia treated by plating The wound broke open exposing the fracture line and the metal plate (A) Although infected the condition of the wound was so much improved by intensive local care (gentle debridement, daily wet dressings and carefully placed gauze packing) that direct closure after removal of the metal plate was successfully achieved by shifting a local double-pedicled flap of adjacent skin and closing the donor site with a free graft (B and C) Note the dimensions of the flap: the relaxing incision of the flap twice *as long as the primary scar and the width of the flap more than half the length of the primary scar*

Two types of open wound are common in the tibial crest One is the jagged roughly circular open wound which must be debrided and may be extended upward and downward to expose and fix the fracture The other is the elliptical wound that develops from the first because of edema of the soft tissues or because of tissue loss in the long axis of the tibia

The first type may be closed above and The flap is rotated medially to cover the exposed fracture line and the donor surface is closed with a skin graft (Fig 560)

The second type of wound because the defect is elliptical in shape rather than circular is best closed with a double-pedicled flap also from the lateral surface of the leg In preparing this flap its size can be very accurately measured (Fig 561) Its width should be *half the length*

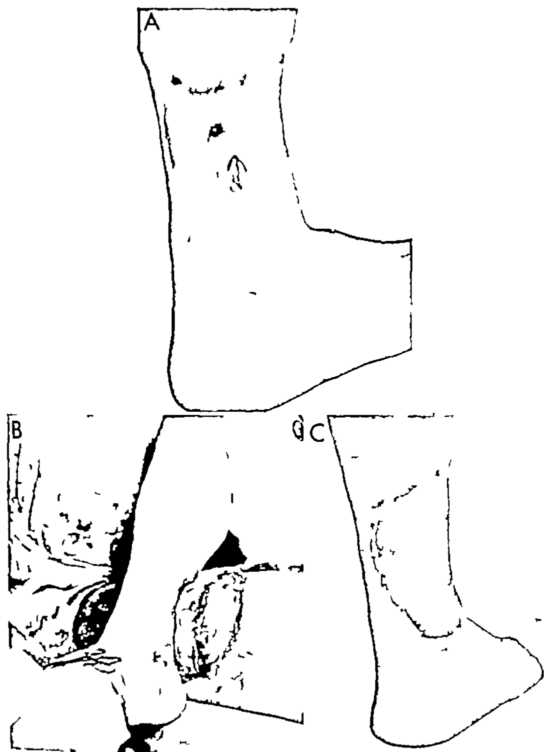


Fig. 562.—Unstable scar of lower leg (A) repaired by direct flap from opposite thigh (B and C) No deep surgery indicated or contemplated (From Cannon B and Trott, A. W: Expeditious use of direct flaps in extremity repairs Plast. & Reconstruct Surg 4 415 1949)



Fig 564 —Severe crushing injury with necrosis of skin and destruction of contents of anterior compartment of the lower leg (A) Operative debridement of all devitalized tissue was carried out within 24 hours and the wound closed immediately with a free skin graft from the opposite thigh (B) The skin graft proved stable except over the ankle joint where it lay directly on the joint surfaces A tubed flap from the abdominal wall with the wrist as the intermediate carrier (C) was transferred in multiple stages to replace the skin graft in the lower half of the

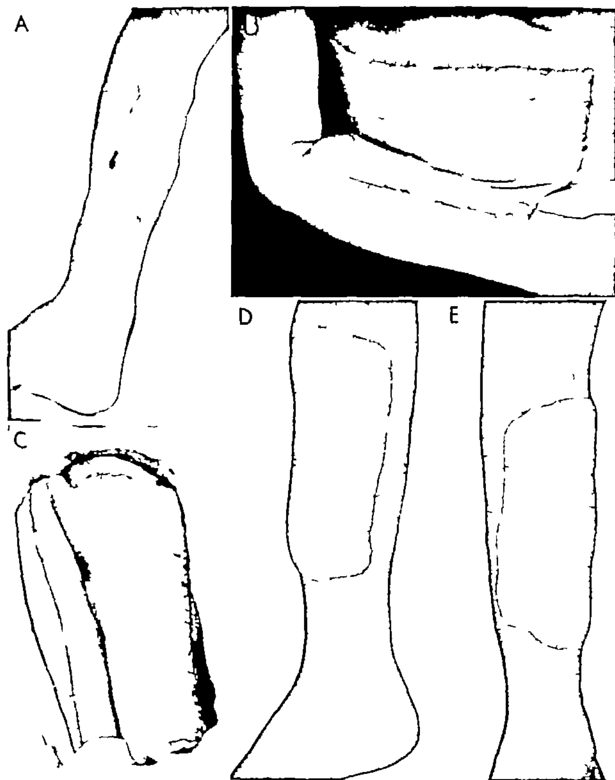


Fig. 565.—Extensive loss of skin on the leg (A) requiring resurfacing of the whole front of the lower leg and covering of the tibia by an open jump flap from the abdominal wall. Seven operations in 12 weeks were required to complete the procedure using the forearm as a direct intermediate carrier (B C) Final appearance (D E) (From Cannon, B Lischer C E. and Brown J B Open jump flap repairs of the lower extremity Surgery 22 335 1947.)

leg and provide a cushion over the ankle joint (D) When the patient began to move the ankle the flap separated from the bone at this level Better anchorage for the flap was secured by drilling multiple holes in the thick bony cortex of the tibia and the talus

cient to pump blood into a flap but if the pedicle is kinked or inadequate the venous outflow which is at a much lower pressure may be impeded. Persistent bluish discol oration of a flap due to venous congestion is often a grave sign of impending necrosis

Flaps particularly from the abdominal wall may need to be thinned after the deep surgery is completed The fat provides a good gliding medium for the repaired or adherent tendons and a good blood supply for bone grafts or nerve suture Sensation returns to flaps in a matter of months if the local nerve supply is intact but if the regional nerve is destroyed anesthesia will persist. Until sensation returns the patient must be warned to avoid injury or trauma of the anesthetic skin

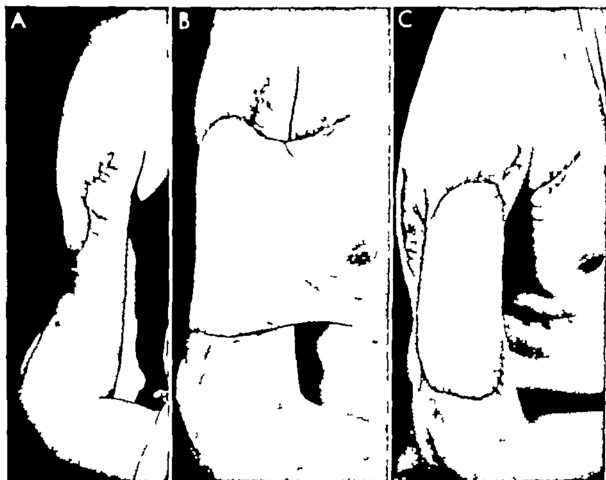


Fig 566 —Soft tissue loss on the lateral surface of the upper arm with interruption of continuity of the humerus (A) Function of the forearm and hand was unimpaired. Direct flap from the chest wall (B and C) was used to provide covering preliminary to successful bone grafting of the humerus (From Cannon B Some Recent Developments in Plastic Surgery S Clin North America 27:1106 1947)

SUMMARY

In evaluating the best method for the surface repair of any extremity the sequence of choices usually is (1) excision of the scar and closure (2) resurfacing with a free-skin graft if the underlying tissue is sufficiently vascular to accept the graft (3) shifting of a single or double-pedicled local flap as either a direct or delayed flap and (4) transfer of remote flaps The skin graft is most useful for closing a primary or early wound at the time of initial debridement for the cover ing of ulcerations in the chronic wound or reducing its size and for repair of the donor area of a flap In the majority of ex tensive repairs necessitated by previous

major deep trauma the use of a remote flap may prove the most rapid and effective method of securing a satisfactory result The primary *indication for the use of a* flap is to replace superficial and deep scars with normal skin and subcutaneous tissue Such replacement is of the greatest impor tance for better protection over bony prom inences for replacement of unstable scar tissue, and for securing healthy tissue through which definitive deep repairs to bone tendon and nerve may be carried out

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36  Chest Injuries

THERE ARE THREE primary considerations in the management of severe chest injuries —two immediate and one late The conditions to be considered are (1) the immediate and often profound disturbances of cardiorespiratory function (2) hemorrhage and (3) the late complications of infection damaged lung and crippled thoracic cage The management of the bony injury is secondary to these important considerations

It is customary in clinical practice to speak of a patient as "doing well." A patient who has suffered a severe chest injury can be said to be "doing well" only if the following criteria are satisfied

1 Resuscitation has been carried out to the extent that significant circulatory disturbances and asphyxia have been relieved.
2. Bleeding has been controlled
3 The chest wall is stable and cough and breathing are painless enough to be effective
4 The respiratory passages are cleared of secretions
5 The pleural cavities are free of significant amounts of blood and air so that both lungs are expanded or expanding
6 External wounds have been satisfactorily debrided and dressed

With these objectives in mind it is possible to construct a clinically useful outline of the management of chest injury Each item will be considered, first, in terms of disturbance of function and, secondly in terms of practical management of that disturbance It is recognized that such separation is an artificial device easier to accomplish on paper than when confronted with a badly injured man

RESUSCITATION

The pulse rate and blood pressure are two vital signs by which the state of shock is estimated and recorded. It is customary to accept a systolic pressure of greater than 90 mm. of mercury and a pulse rate of less than 100 as satisfactory Such measurements must be interpreted with reference to the individual patient and are no substitute for a complete clinical appraisal which includes the degree of pallor and coolness of the skin the quality of the pulse the width of the pulse pressure and the rate of urinary output Furthermore it must be remembered that in a serious chest injury the classic signs of shock that are ordinarily ascribed to an inadequate circulating blood volume may in fact result from some totally different cause such as for example a positive-pressure pneumothorax cardiac tamponade or even direct cardiac injury On the other hand, blood loss may be concealed for exsan-

guination into a pleural cavity may occur without great embarrassment to respira tion. A patient may also be bleeding from an upper abdominal organ that has been damaged at the time of the chest injury The spleen demands special consideration

It is clear that accurate diagnosis is of paramount importance in the treatment of shock associated with serious chest injury Failure to recognize a positive pressure pneumothorax or cardiac tamponade may be disastrous In the absence of serious intrapleural, intra abdominal or external bleeding transfusions must be given cau tiously When transfusion is necessary the need is for whole blood with its oxy gen-carrying ability and not for a "blood substitute" The question of fluid balance if there is no serious associated abdominal injury usually causes little concern Many patients can take adequate amounts of fluid by mouth and are as a practical mat ter best kept a little "dry" on the assump tion that they will very quickly readjust their fluid balance as recovery takes place

A second important aspect of resuscita tion is the relief of hypoxia usually evi denced by cyanosis The dangers of hy poxia to the brain and to the heart are well established Hypoxia may be a major contributing cause of the "shock" state Practically the relief of cyanosis demands the administration of large amounts of oxygen while the various contributing causes of the hypoxia are corrected. The latter will be considered later under man agement of the chest wall the airway and the pleural space

The method of high-oxygen administra tion depends on the equipment available Oxygen by mask is very effective and of particular value in the ambulance or emer gency room phase of the patient s manage- ment. An ordinary anesthetic mask is adequate although specially designed masks may be used Adequate oxygen may be given by nasal catheter usually at the rate of 6 liters per minute but this method of administration is less efficient than the mask. Oxygen by nasal catheter however is well tolerated and simplifies nursing care But it has two drawbacks First oxy gen saturated by being bubbled through water at room temperature (20 C) is rel atively dry when heated to body temper ature (37 C) in the pharynx This dry ness is irritating and tends to make the tracheal secretions sticky Such dryness may be avoided by adding a warming unit to the humidifying chamber Second a constant flow of gas into the pharynx may accentuate the effect of air swallowing and increase abdominal distention which is frequently troublesome in the injured pa tient The use of a humidified oxygen tent obviates some of the difficulties of the ad ministration of oxygen by nasal catheter but it introduces other problems of nursing care expense and availability of equip- ment

CONTROL OF BLEEDING

Control of bleeding is axiomatic in the management of any severe injury The problem in chest injury is to identify the source of the bleeding and to decide whether or not it is continuing

Arterial bleeding into the chest may be from two sources low pressure bleeding from the pulmonary circuit or high-pres- sure bleeding from a systemic artery usu ally an intercostal artery In addition there may be troublesome and dangerous hemorrhage from a systemic vein which is held open by bone injury and is bleeding into an enormous body cavity

Bleeding from the lung is of low pres- sure variety and once stopped is not prone to begin again Such bleeding is not likely to be affected by re-expansion of the lung Systemic bleeding is of high pressure is largely independent of the state of the lung and is poorly tamponaded by a mas sive hemothorax. Aspiration of a hemo- thorax is therefore logical and advisable as a means of both re-expanding a lung and determining the status of bleeding

Ordinarily the detection of blood in the pleural space is not difficult particularly if even the simplest of x ray facilities are available Aspiration should be carried out

with a wide-bore needle (No 18 gauge will usually suffice) Although the blood thus removed can theoretically be used as an autotransfusion as a practical matter this procedure is rarely indicated if adequate bank blood is available Evidence of continuing hemorrhage demands prompt thoracotomy

Thoracotomy in the presence of severe chest injury particularly damage to the lung may present a serious problem of anesthesia. The respiratory effort attendant on the induction and insertion of an intra tracheal tube in addition to the maintenance of positive-pressure breathing may lead to the accumulation of air in the pleural space with the rapid development of a tension pneumothorax Under these circumstances the operator may be forced to open the chest precipitously in order to control a dangerous pneumothorax Once the chest has been opened dangerous intrapleural pressure is no longer possible and the operation can proceed at a more deliberate pace

STABILIZATION OF THE CHEST WALL

To be effective a chest wall must be not only relatively rigid but also painless enough to permit cough and ventilation

A certain rigidity of the chest wall is essential otherwise paradoxical motion of the chest occurs Under the latter circum stances the chest wall is drawn in on in spiration and bulges outward on expiration As a result the bellows-like action of the thorax is abolished and the underlying lung is not ventilated In extreme cases the lung on the affected side may become the air space from which the contralateral lung is ventilated This the phenomenon of "pendulum-air" is illustrated in Figure 567 Whatever its practical importance the concept of pendulum air serves to em phasize the dangers of the "stove-in" or "flail" chest.

Paradoxical motion of an injured chest usually presupposes that the rib cage has been broken anteriorly and posteriorly The latter is usually apparent in the roentgenogram and the former in the physical ex amination. A special situation may occur in the case of impact injury to the sternum (the common steering-post injury) where bilateral anterior fractures are present.

Lesser degrees of paradoxical motion may be controlled by supporting bandages, light-shot bags and similar splinting, so long as total immobilization of the thorax is avoided Severe crushing injuries may require internal fixation by wiring, al though this is not ordinarily necessary A depressed and mobile sternum may require elevation and fixation secured by traction exerted through a towel clip or similar instrument firmly inserted into the sides of the sternum

Of great practical importance in the management of chest injuries is the control of pain without suppression of cough. The pain of chest injury is likely to be so severe that morphine and kindred agents can produce relief only at the price of dangerous depression of the respiratory center and the cough reflex A great deal has been written about the "wet lung of trauma," and nebulous chest wall–pulmonary reflexes have been described It seems unnecessary to look further than the inhibitory effects of pain upon cough and ventilation.

The extraordinary pain of chest injury should be treated by intercostal block, repeated if necessary Ordinarily long acting local anesthetics and alcohol injection are not advisable in view of the unpredicta bility of late neuritis

The technique of intercostal block is simple Skin wheals are raised posterior to the angle of the ribs to be blocked usually two or three ribs above and below the level of pain. Through the skin wheal a 1 inch No 22 needle is inserted down to the un derlying rib and the angle is then shifted so that the needle tip slides a few millimeters below the lower border of the rib Aspiration at this point will determine that the needle does not lie within an intercostal vessel or within the pleural space After

this check 3–5 cc of 2 per cent procaine is injected It is important to remember that this maneuver is not infrequently fol lowed by a pneumothorax—if this did not already exist as a result of the original in jury Such a pneumothorax is not a serious complication if recognized and treated promptly When the block is carried out close to the neck of rib it is in reality a paravertebral block. Under these circum stances great care must be exercised not to introduce the anesthetic agent intra spinally along the dorsal nerve roots is to encircle the patient s chest with a bath towel The patient then grasps the ends of the towel with crossed hands in front of his chest tightening the encircling towel each time he coughs It is remarkable how effective this simple maneuver can be

MAINTENANCE OF A CLEAR AIRWAY

In the preceding section the importance of insuring an effective cough was empha sized By coughing the patient manages to keep his tracheobronchial tree clear of

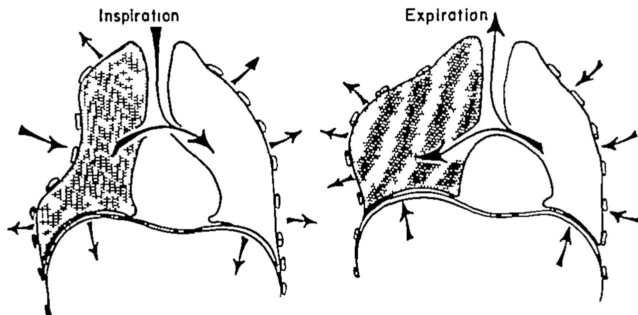


Fig. 567 —Diagram illustrating the hazards of paradoxical motion of the chest wall. Vol ume of the involved side is *reduced* on inspiration and ventilation of the uninjured side may be to and from the injured side—i.e "pendulum air"

Tight adhesive strapping has little place in the treatment of fractured ribs although light support with an elastic adhesive ban dage may provide symptomatic relief A chest binder may make the patient more comfortable and so long as it is not tight or constricting there is no objection to its use A great deal can be accomplished by intelligent nursing care and this in turn will depend on instruction from the sur geon in charge The nurse should be in structed to splint the patient s chest with extended hands and to encourage the pa tient to cough against this support which is both moral and physical A useful trick

secretions To administer oxygen to a pa tient who is drowning in his own secretions is remarkably futile Furthermore the ac cumulation of tenacious secretions in the smaller branches of the bronchial tree leads to atelectasis and presumably facil itates the development of bronchopneu monia. If the patient is unable to keep his airway clear active steps must be taken to help him In order of simplicity these are (1) tracheal aspiration by catheter (2) bronchoscopic aspiration and (3) trache otomy

The proper use of tracheal aspiration is so important that a few words about tech

nique are in order It is best to use a relatively firm catheter—for example a new red rubber 16 F Fairly strong suction is required and this is applied to the catheter by a Y or a T tube so that intermittent suction can be obtained by occluding and releasing the side-arm vent. To minimize the gag reflex, topical anesthesia of the pharynx with 4 per cent cocaine or a similar agent may be used Cocainization of the larynx will facilitate the passage of the catheter but is not necessary If the patient can co-operate he is given a gauze sponge and is instructed to pull his tongue out thereby tilting the epiglottis forward The operator then inserts the lightly lubricated catheter into the patient's nostril. If it is advanced only during inspiration—particularly inspiration that immediately follows a forced cough—the catheter will enter the trachea. The patient must be urged not to swallow otherwise the tube will almost certainly enter the esophagus The entrance of the catheter into the trachea is heralded by pronounced coughing The catheter is then advanced first into one major bronchus then into the other suction being applied intermittently If the patient's head is turned to the left the catheter will enter the right main bronchus and vice versa. Tracheal suction though not pleasant should not be an excessively uncomfortable and dreaded procedure Its immediate effect is often dramatic

If the trachea cannot be kept clear by catheter suction bronchoscopy is indicated If a chest injury is severe enough to require bronchoscopy and particularly repeated bronchoscopies then serious consideration should be given to tracheotomy Tracheotomy is often lifesaving in the management of secretions when there is an associated severe head injury but its use should not be reserved for such extreme cases With a tracheotomy it is possible to keep the airway clear at all times with a minimum of disturbance to the patient. If at the same time respiratory dead space is decreased and ventilation is rendered more efficient so much the better

MANAGEMENT OF BLOOD AND AIR IN THE PLEURAL SPACE

One of the primary objectives of treatment in chest injuries is to expand the lung on the involved side and to restore the normal intrathoracic dynamics as soon as possible This is most obvious if a positive-pressure pneumothorax is present.

A positive-pressure or tension pneumothorax is the result of a valvular leak *into* an otherwise closed pleural space With a closed injury this leak is usually from the parenchyma of the lung although it may be from a major bronchus the trachea, and on rare occasions from the esophagus Very often, as a lung collapses a tear in its surface will seal but if it does not, a dangerous degree of positive intrapleural pressure may develop which by displacing the mediastinum away from the injured side may encroach upon the other presumably uninjured lung. In addition to producing respiratory embarrassment, positive intrathoracic pressure may seriously interfere with venous inflow into the chest and therefore into the heart with a resultant lowering of the cardiac output to dangerous levels The treatment is to create a valvular leak *out* from the pleural space.

The diagnosis of a tension pneumothorax may be confirmed by roentgenogram, but the latter is not needed to make the diagnosis Respiratory embarrassment tracheal shift away from the injured side absent breath sounds and particularly subcutaneous emphysema following injury confirm the diagnosis and demand prompt action. The first step is needle aspiration, most easily done in the second or third interspace anteriorly about 2 inches lateral to the border of the sternum, so as to avoid injury to the internal mammary vessels. This is an emergency procedure It is usually wise in civilian hospital practice to institute prompt closed drainage by intercostal catheter in almost every traumatic pneumothorax which presents itself with positive pressure or which reaccumulates after one aspiration

For closed drainage an 18 F or 20 F catheter is inserted by means of a trocar through the second or third intercostal space anteriorly The catheter is then connected to three bottle suction (Fig 568) or to water seal drainage (Fig 569) Intelligently used either form of drainage is satisfactory When available three-bottle ally after 48 hours the leak in the lung has sealed and the lung itself has expanded or is expanding satisfactorily

The management of blood in the pleural space may present greater practical difficulties than the management of air There are many compelling reasons for aspirating a hemothorax of significant amount

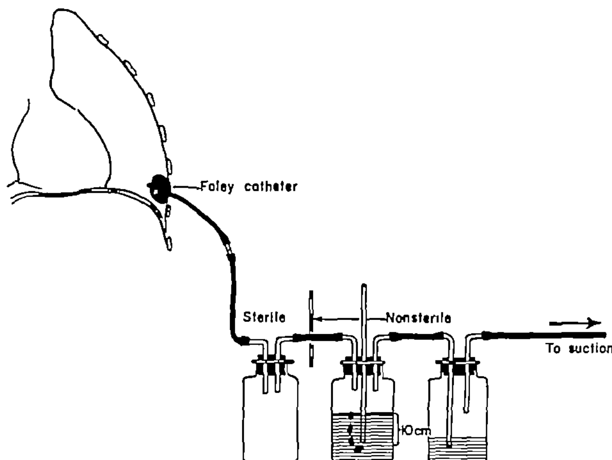


Fig 568 —Diagram of a satisfactory method of chest suction. The center bottle serves as a safety valve to prevent the suction in the system from reaching unphysiological levels The first bottle is merely a trap The third bottle acts as a water-seal valve in case the suction tubing is disconnected from its source

suction is preferable since it insures a continuous "negative" pressure of a known degree The danger of reopening a leak in an injured lung by suction is more fancied than real.

Forty-eight hours of closed drainage is ordinarily adequate After that time the danger of introducing infection along the tube is increased partly related to the difficulty of maintaining an airtight closure of the chest wall around the catheter Usu

In the first place it is important to relieve so far as possible any encroachment on the lung Secondly as already stated it is essential to determine the source and status of intrathoracic bleeding A third reason is the avoidance of the late crippling effects of fibrothorax.

It is obviously important to define a "significant" hemothorax Certainly this term will include any hemothorax detectable by physical examination It will also

nique are in order It is best to use a relatively firm catheter—for example a new red rubber 16 F Fairly strong suction is required and this is applied to the catheter by a Y or a T tube so that intermittent suction can be obtained by occluding and releasing the side-arm vent. To minimize the gag reflex, topical anesthesia of the pharynx with 4 per cent cocaine or a similar agent may be used Cocainization of the larynx will facilitate the passage of the catheter but is not necessary If the patient can co-operate he is given a gauze sponge and is instructed to pull his tongue out thereby tilting the epiglottis forward The operator then inserts the lightly lubricated catheter into the patient's nostril. If it is advanced only during inspiration—particularly inspiration that immediately follows a forced cough—the catheter will enter the trachea. The patient must be urged not to swallow otherwise the tube will almost certainly enter the esophagus The entrance of the catheter into the trachea is heralded by pronounced coughing The catheter is then advanced first into one major bronchus then into the other suction being applied intermittently If the patient's head is turned to the left, the catheter will enter the right main bronchus and vice versa. Tracheal suction though not pleasant, should not be an excessively uncomfortable and dreaded procedure Its immediate effect is often dramatic.

If the trachea cannot be kept clear by catheter suction bronchoscopy is indicated If a chest injury is severe enough to require bronchoscopy and particularly repeated bronchoscopies then serious consideration should be given to tracheotomy Tracheotomy is often lifesaving in the management of secretions when there is an associated severe head injury but its use should not be reserved for such extreme cases With a tracheotomy it is possible to keep the airway clear at all times with a minimum of disturbance to the patient. If at the same time respiratory dead space is decreased and ventilation is rendered more efficient, so much the better

MANAGEMENT OF BLOOD AND AIR IN THE PLEURAL SPACE

One of the primary objectives of treatment in chest injuries is to expand the lung on the involved side and to restore the normal intrathoracic dynamics as soon as possible. This is most obvious if a positive-pressure pneumothorax is present

A positive-pressure or tension pneumothorax is the result of a valvular leak *into* an otherwise closed pleural space With a closed injury this leak is usually from the parenchyma of the lung although it may be from a major bronchus the trachea and on rare occasions from the esophagus Very often, as a lung collapses a tear in its surface will seal but if it does not, a dangerous degree of positive intrapleural pressure may develop which, by displacing the mediastinum away from the injured side may encroach upon the other presumably uninjured, lung In addition to producing respiratory embarrassment, positive intrathoracic pressure may seriously interfere with venous inflow into the chest and therefore into the heart with a resultant lowering of the cardiac output to dangerous levels The treatment is to create a valvular leak *out* from the pleural space

The diagnosis of a tension pneumothorax may be confirmed by roentgenogram but the latter is not needed to make the diagnosis Respiratory embarrassment, tracheal shift away from the injured side absent breath sounds and particularly subcutaneous emphysema following injury confirm the diagnosis and demand prompt action The first step is needle aspiration most easily done in the second or third interspace anteriorly about 2 inches lateral to the border of the sternum so as to avoid injury to the internal mammary vessels. This is an emergency procedure It is usually wise in civilian hospital practice to institute prompt closed drainage by intercostal catheter in almost every traumatic pneumothorax which presents itself with positive pressure or which reaccumulates after one aspiration

For closed drainage an 18 F or 20 F catheter is inserted by means of a trocar through the second or third intercostal space anteriorly The catheter is then connected to three-bottle suction (Fig 568) or to water-seal drainage (Fig 569) Intelligently used either form of drainage is satisfactory When available three bottle suction is preferable since it insures a continuous "negative" pressure of a known degree. The danger of reopening a leak in an injured lung by suction is more fancied than real.

Forty-eight hours of closed drainage is ordinarily adequate After that time the danger of introducing infection along the tube is increased partly related to the difficulty of maintaining an airtight closure of the chest wall around the catheter Usually after 48 hours the leak in the lung has sealed and the lung itself has expanded or is expanding satisfactorily

The management of blood in the pleural space may present greater practical difficulties than the management of air There are many compelling reasons for aspirating a hemothorax of significant amount. In the first place it is important to relieve so far as possible any encroachment on the lung Secondly as already stated it is essential to determine the source and status of intrathoracic bleeding A third reason is the avoidance of the late crippling effects of fibrothorax.

It is obviously important to define a "significant" hemothorax. Certainly this term will include any hemothorax detectable by physical examination It will also

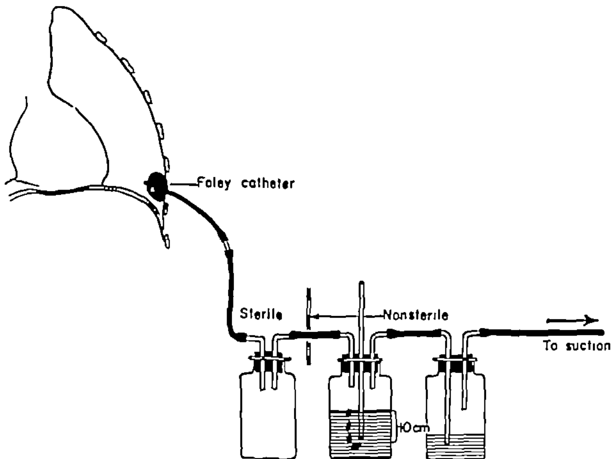


Fig 568 —Diagram of a satisfactory method of chest suction The center bottle serves as a safety valve to prevent the suction in the system from reaching unphysiological levels The first bottle is merely a trap The third bottle acts as a water-seal valve in case the suction tubing is disconnected from its source

include one that produces 25 per cent col lapse of the underlying lung or which may be estimated, by x ray examination to ex ceed 500 cc It will of course include any hemothorax that increases to an appreci able extent while under careful observation closed drainage by way of an intercostal catheter

The method of closure of the chest wound depends on the exigencies of the situation and the facilities available Under emergency conditions a voluminous gauze dressing, firmly applied with a layer of petrolatum impregnated gauze protecting the exposed tissues provides adequate oc clusion Subsequently this dressing may be removed the wound debrided and an an atomical layer closure of the chest wall carried out. At the time of definitive clo sure associated injuries to the lung and thoracic contents may be dealt with If the latter are extensive a separate incision may be necessary for adequate exposure. The surgeon should not feel compelled to limit his choice of incision to the one that an unkind fate has provided

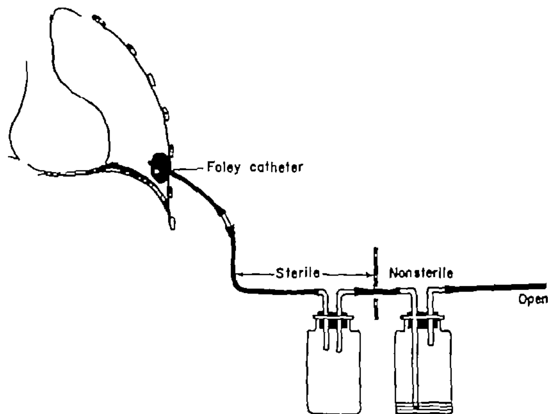


Fig 569 —Diagram of water-seal drainage The sterile bottle acts as a trap and prevents *siphonage of water into the chest if the apparatus should be lifted above the level of the pa tient s chest*

MANAGEMENT OF THE EXTERNAL WOUND

The care of the external chest wound follows the principles that apply to wounds of the soft parts in general in addition to the problem of the external wound that communicates with the pleural space—the so-called "sucking wound " Prompt closure is mandatory but certain precautions are necessary in order to insure that there is no underlying wound of the lung which may lead to a pressure pneumothorax when the external wound is closed The principle here is to close the external wound but to provide at the same time for

The important practical point to remem

ber is that the emergency dressing should not be applied so tightly as to prevent the escape of air should a positive pressure pneumothorax develop The dressing should function as an effective flap valve

SPECIAL CONSIDERATIONS

No discussion of chest trauma would be complete without some mention of cardiac tamponade and direct cardiac injury both of which may be the result of the most common form of severe injury today—the automobile accident The classic situation is the steering post injury with a depressed fracture of the sternum or anterior chest wall.

Cardiac tamponade results when there is a rapid accumulation of blood or fluid within the pericardial sac. This structure is comparatively inelastic and can accom modate relatively little fluid without a sharp rise in intrapericardial pressure The latter is immediately transmitted to the thin walls of the low pressure atrial cham bers and great veins and by encroaching on these structures greatly impedes the inflow of blood to the heart. In addition the presence of significant amounts of in trapericardial fluid under increased pres sure will seriously hinder diastolic filling of the ventricles Both factors—impedance of venous inflow and interference with di astolic filling—in turn lead to seriously diminished cardiac output and great increase in peripheral venous pressure The latter can be measured directly and is apparent on inspection of the neck veins The former produces a gradually narrow ing pulse pressure tachycardia, and even tual fall of systolic pressure The situation may rapidly become critical Interference with venous inflow into the heart also leads to the appearance of a paradoxical pulse—really an accentuation of the normal—where the systolic pressure falls with inspiration When marked this phenom enon can be appreciated by careful palpa tion of the radial pulse throughout the phases of respiration.

In acute cardiac tamponade roentgen ograms of the chest are of limited value since by the nature of the phenomenon the pericardial sac will not have dilated rapidly When the clinical suspicion of cardiac tamponade exists and when a clinical rec ord of pulse and blood pressure shows the situation to be deteriorating pericardial tap should be carried out This is most easily done through the left costoxiphoid angle directing a short bevel 2½ inch No 19 needle upward and inward after preliminary infiltration with procaine solution In this region the pericardium is fused with the fibrous sheath of the diaphragm The latter structure is easily indentified by the exploring needle

Pericardial tap will usually produce im mediate relief of tamponade Should the latter recur and repeated pericardial taps become necessary surgical exploration of the pericardium is indicated

Direct cardiac injury as a result of an terior chest wall trauma is not common but may occur Temporary electrocardiographic changes especially in the T waves may follow a penetrating or contused lesion of the heart muscle Just how common and how serious "steering wheel cardiac contusion" may be is not clearly known

SUMMARY

No attempt has been made here to cat alogue all possible forms and degrees of chest injury On the contrary an effort has been made to present a clinically useful outline with a brief discussion of each of the major disturbances of function encountered as well as practical suggestions of how to manage each aspect Obviously each surgeon may argue his own personal preferences but there should be funda mental agreement on the objectives of treatment In summary these are

1 Prompt resuscitation
2 Control of serious hemorrhage
3 Restoration of a stable and painless chest wall
4 Maintenance of a clear airway

5 Removal of blood and air from the pleural space
6 Satisfactory closure of the external wounds

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37  Management of Abdominal Injuries

THE PURPOSE of this chapter is to outline the principles of general supportive treat ment and of technical management of in dividuals sustaining abdominal visceral in juries Consideration of these problems is important to both military and civilian sur geons although different types of injuries are encountered in war and peace

GENERAL CONSIDERATIONS

FREQUENCY OF ABDOMINAL INJURIES

Military experience in the Korean War showed that approximately 11 per cent of all men wounded in action suffered ab- dominal injuries nearly all of which were penetrating wounds During World War II the Second Auxiliary Surgical Group treated approximately 22 000 casualties 3 154 (13 0 per cent) of whom sustained abdominal trauma of these abdominal in juries 99 5 per cent were penetrating wounds In civilian practice abdominal in juries resulting from falls or athletic in dustrial, and traffic accidents usually involve blunt trauma—in contrast to the penetrating wounds of military experience Of all abdominal wounds treated at the Massachusetts General Hospital during the years 1930–53 (282 cases) only 16 3 per cent were caused by penetrating injuries while 83 7 per cent were caused by blunt trauma (Table 29)

TABLE 29 —TYPES OF ABDOMINAL INJURIES (282 CASES)

Penetrating	
Bullets	18
Stab	21
Other	7
Total	46 (16.3%)
Blunt	
Falls	93
Automobile	69
Other	74
Total	236 (83 7%)

TYPES OF ABDOMINAL INJURIES

Of considerable interest is the contrast between the visceral injuries in military practice and those in civilian practice In the series observed at the Massachusetts General Hospital, 40 7 per cent of the wounds involved the kidneys 22 7 per cent involved the spleen and 8 5 per cent the liver while only 15 3 per cent injured any portion of the gastrointestinal tract (Table 30) In contrast World War II experience of the Second Auxiliary Surgical Group in

5 Removal of blood and air from the pleural space

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Physical Signs

The local physical signs which may indicate underlying visceral injury are tenderness spasm absence of liver dullness diminished or absent peristaltic sounds and shifting dullness These observations should always be supplemented by digital rectal examination catheterization if the patient is unable to void promptly and the insertion of a nasogastric tube to study the character of the gastric contents Both the catheter and the nasogastric tube should be left in place allowed to drain and the specimens examined for gross and microscopic evidence of blood The finding of blood on digital examination of the rectum indicates that sigmoidoscopy should be done

Other signs which should be carefully noted include the rate and character of respiration rate and quality of the pulse and the blood pressure A rising pulse rate may be the earliest indication of intra abdominal hemorrhage and this may be confirmed by a later decline in blood pressure readings In this regard it is helpful in the case of a severely wounded patient to have a chart of the patient s vital signs recorded at intervals of 15–30 minutes over the first few hours of observation It may be assumed that shock occurring early after injury is due to blood loss alone but after the lapse of a few hours sepsis and *peritonitis* may contribute to the advancing picture of shock in a patient with visceral injuries Occasionally abdominal paracentesis will disclose evidence of hemorrhage but if the examination is negative the surgeon must realize that the patient may still be bleeding internally

X ray Examination

The early employment of x-ray aids to diagnosis is mandatory Plain and erect films of the abdomen may give evidence of a foreign body splenic or hepatic enlargement obliteration of the psoas shadows or free gas in the peritoneal cavity If the patient is too ill to withstand being placed in the semierect position of a tilting table a film in the lateral decubitus may be substituted to demonstrate splenic enlargement or serrated filling defects along the greater curvature of the stomach secondary to hemorrhage into the gastrosplenic ligament The finding of fractures in the lower thoracic cage on either side fractures of the bodies or transverse processes of the spine or fractures of the pelvis may give further hints as to the possible nature of underlying visceral injuries Thus fractures of the left lower ribs should raise the suspicion of damage to the spleen of the right lower ribs the liver Fractured transverse processes of vertebrae D8 through L2 are often accompanied by injury to the kidney and fractures of the pelvis by bladder or urethral damage

If more than a few red blood cells are found on urinalysis an intravenous pyelogram should be done as soon as feasible in order to discover whether one or two kidneys are present and to determine accurately the degree of renal damage Even in an unprepared patient this study will demonstrate the presence or absence of gross damage to the kidney

GENERAL TREATMENT

Early Treatment

Consideration of the diagnostic maneuvers outlined should not result in neglect of the evaluation of the patient as a whole and the data obtained should be carefully studied with respect to the patient s general condition and all other associated injuries Attention is directed to Chapter 9 in which the problem of priority to be accorded various multiple injuries is discussed Nor should treatment of a severely wounded patient be neglected until all diagnostic studies are completed. Diagnosis and treatment should proceed together in a smooth integrated fashion in order to maintain maximum efficiency in the handling of these complicated emergencies

dicated that 13 5 per cent of abdominal wounds involved the kidney 10 8 per cent the spleen 27 0 per cent the liver and 85 3 per cent some part of the gastrointestinal tract. Thus as a general rule blunt trauma affects the solid viscera more frequently while penetrating trauma injures the abdominal organs with a frequency directly proportional to the space these organs occupy within the abdominal cavity

TABLE 30 —FREQUENCY OF VISCERAL INJURIES IN 282 CIVILIAN CASES

	Injury	No. of Cases	Incidence (Per Cent)
1	Kidney	115	40 7
2.	Spleen	64	22.7
3.	Abdominal wall	32	11.3
4	Liver	24	8.5
5	Small bowel	18	6.4
6.	Colon	18	6 4
7	Mesentery	11	3 9
8	Bladder	10	3.5
9	Retroperitoneal hematoma	8	2.8
10	Stomach	7	2.5
11	Urethra	5	1.8
12.	Rectum	2	0 7
13	Ureter	1	0 4

It is readily apparent that every penetrating wound of the abdominal wall may be associated with visceral injuries Although it is not so evident any penetrating wound of the chest back, buttocks or thigh may also injure the abdominal viscera. In assessing this possibility it is helpful to determine the course of the missile or instrument responsible for the injury There is universal agreement that penetrating wounds of the abdomen require exploration at the earliest moment permitted by the patient s general condition

Unfortunately the need for early abdominal exploration is not so evident in the case of blunt injuries as it is with penetrating wounds As a consequence all reported series show higher mortality rates for blunt abdominal trauma than for penetrating injuries In the experience of the Massachusetts General Hospital the mortality in the former instance is 11 9 per cent while in the latter it is 4 3 per cent (Table 31) The preponderance of blunt injuries in civilian practice implies a need for the utmost vigilance on the part of surgeons dealing with such cases

TABLE 31 —MORTALITY BY YEARS AND TYPE OF TRAUMA

	No. of Cases	No. of Deaths	Percentage of Mortality
Blunt trauma *			
1930–37	57	11	19.3
1938–42	59	11	18.6
1943–47	56	2	3.6
1948–53	64	4	6.3
Total	236	28	11.9
Penetrating injuries †			
1930–37	11	2	19 1
1938–42	8	0	0 0
1943–47	9	0	0 0
1948–53	18	0	0.0
Total	46	2	4.3

* Includes 1 case without recognizable visceral damage at laparotomy

† These include 3 cases in which the peritoneum was not entered by trauma (knife, bullet) but exploratory laparotomy was performed.

SYMPTOMS AND SIGNS OF ABDOMINAL INJURIES

Symptoms

As a preface to the discussion of management of abdominal injuries it should be pointed out that, in the presence of multiple severe injuries symptoms and signs of abdominal visceral injury are far less dramatic than are those of fractures vascular wounds or head injuries To avoid serious errors the surgeon in charge of a case of an abdominal injury must study the patient carefully and repeatedly for the insidious development of clues to internal visceral damage The symptoms of abdominal injuries include pain nausea, vomiting hematemesis hematuria, melena a feeling of apprehension thirst and air hunger but the outstanding symptom is pain The pain may be of any degree from mild to severe it may be localized or generalized over the entire abdomen; or it may be referred to the back or to the shoulders (as a manifestation of diaphragmatic irritation) In the unconscious patient, the surgeon is of course deprived of this aid to diagnosis

Physical Signs

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The initial treatment of abdominal injuries is supportive The patient should be kept recumbent and covered but without added artificial heat. If the blood pressure is subnormal, a moderate Trendelenburg position is desirable to encourage maximum oxygen transport to vital organs Prompt administration of whole blood should be carried out to maintain adequate circulating blood volume This should be supplemented by giving oxygen through a nasal catheter at a rate of 6–8 liters per minute

Antibiotics

There can be no doubt that the use of antibiotics has greatly decreased mortality from abdominal injuries and it is the best policy to begin the administration of these agents as soon as a strong suspicion of visceral injury exists Usually unless the patient has been sensitized previously penicillin and streptomycin in doses of 300 000 units and 0 25 Gm respectively are administered intramuscularly every 3–6 hours This therapy is continued through the operation and for 5 days postoperatively unless the patient s condition indicates that the drugs are ineffective In such a case intravenous Aureomycin® Terramycin® and Achromycin® in dosages of 1 0 Gm per day may be substituted

Gastric Aspiration

A Levin tube left in the stomach and allowed to drain will reduce the danger of aspiration of gastric contents during operation help reduce peritoneal contamination and aid in the prevention of postoperative ileus and wound dehiscence At times however a Levin tube will not collapse the stomach completely particularly if a large meal has been ingested shortly before the injury The stomach should then be emptied by forced vomiting or by the insertion of a large gastric tube before induction of anesthesia. Removal of large food particles may be aided by saline irrigation

Urinary Drainage

A Foley catheter should be placed on gravity drainage thus providing immediate evidence of continuing or new hematuria and giving an accurate index of urine output.

Laparotomy

Attention must now be turned to the most effective measure available in the treatment of abdominal injuries—abdominal exploration. As noted earlier abdominal exploration is indicated in every case of penetrating trauma Finer surgical judgment is required to determine whether patients with blunt abdominal injuries should be explored or carefully observed

In general exploration is indicated whenever there is reasonable evidence of injury to an abdominal viscus Free gas in the peritoneal cavity hematemesis or aspiration of blood through the Levin tube and bleeding by rectum are clues to such an injury particularly when associated with signs of peritoneal irritation and shock Injuries to the liver and spleen are more difficult to diagnose but laparotomy should be carried out when pain peritoneal irritation or shock create a strong suspicion of such injuries Although most injuries of the urinary tract should be managed conservatively operation should be performed promptly when the urethra has been ruptured and it is not possible to insert a catheter when the bladder has been ruptured (as evidenced by inability to recover sterile saline instilled per catheter) or when severe disruption of one kidney is associated with evidence of severe and continuing hemorrhage

In either event whether the trauma is blunt or penetrating, timing of the exploration is of the utmost importance Laparotomy should be carried out as promptly as the patient s general condition will permit Ideally this should be within 6 hours of the trauma since the mortality rate rises rapidly if operation if delayed longer than

that interval In the presence of serious intra abdominal hemorrhage undesirable delay may be occasioned by an attempt to restore the patient s blood pressure to a normal level by preoperative transfusions This policy is wasteful of blood and increases the degree of peritoneal contamination because of the delay involved If the patient s systolic pressure is 80 mm of mercury and rising and if his skin is warm and dry it is preferable to proceed at once with the operation in order to stop the internal hemorrhage directly The administration of 1 500 cc of whole blood should suffice to prepare most patients for operation

Anesthesia

Preoperatively atropine and pentobarbital sodium should be given While narcotic drugs may be required for the relief of pain and restlessness in the severely injured patient they should be used *only* for this purpose and used sparingly and with caution. The injudicious use of morphine may mask important physical signs and lead to dangerous respiratory depression As pointed out by Beecher morphine if given is best administered intravenously in small doses in these circumstances—lest an accumulation of the drug in the subcutaneous tissues should cause serious depression when absorption is favored by a restored circulating blood volume The use of morphine in cases complicated by head injuries is contraindicated.

With respect to the choice of anesthetic nitrous oxide with oxygen and ether administered through an endotracheal tube seems to be the safest agent available If it is suspected that the stomach has been incompletely emptied preliminary cocainization of the larynx and trachea and the use of a cuffed endotracheal tube diminish the danger of aspiration. Spinal anesthesia favors the further development of shock in the severely wounded patient Pentothal® sodium does not give sufficient muscular relaxation to allow its use as the primary anesthetic agent in dealing with abdominal wounds Regardless of the anesthetic agent chosen the circumstances require good muscular relaxation in order to permit thorough abdominal exploration combined with a high level of oxygen administration

Incisions

Maximum exposure and maneuverability can usually be gained from a paramedian incision which is placed to avoid any wounds of entry or exit on the abdominal wall in order to reduce the dangers of wound sepsis and dehiscence Careful closure of this incision by layers with the use of frequent additional deep retention sutures to catch the deep fascia is recommended Only at the conclusion of closure of the laparotomy wound should the surgeon debride wounds of entry or exit and this debridement should envisage excision of all such wounds with careful layer closure If a colostomy should be necessary it is better to bring the bowel out through an incision separate from the laparotomy wound and the same principle should be followed in the placement of drains

In thoracoabdominal injuries the paramedian incision may be carried laterally across the costal margin and continued in the bed of the eighth or ninth rib or as an intercostal incision as the circumstances require

Control of Hemorrhage

Once access is gained to the peritoneal cavity accumulated blood and intestinal contents are suctioned out and first priority is given to the control of hemorrhage Severe hemorrhage following blunt trauma usually originates from the spleen or liver with penetrating wounds the mesentery of the small bowel or large retroperitoneal vessels may be the source as well. If a *splenic laceration is found the hemorrhage may* be controlled by rolling the spleen forward from its bed grasping the splenic pedicle between the thumb and forefinger

of the left hand Hemorrhage from the liver may be controlled by gauze packing and manual pressure occasionally this will have to be supplemented by temporary digital occlusion of the vessels of the porta hepatis by inserting a finger into the foramen of Winslow If a rent in the small bowel mesentery is found the hemorrhage should be controlled by digital compression of the involved vessels until the serosa of the mesentery can be incised, the hematoma evacuated and accurate visualization of the severed vessels assured

Control of Fecal Contamination

Of importance secondary only to the staunching of hemorrhage is the control of fecal contamination. Since the liquid content of the right colon is more toxic to the peritoneum than the content of any other portion of the intestinal tract exploration is begun here and carried throughout the length of the colon and rectum. If necessary for adequate visualization, the hepatic and splenic flexures are mobilized from their attachments The ileocecal valve is then identified and exploration is carried upward throughout the extent of the small bowel the duodenum and the stomach If any suspicion of duodenal injury exists the lateral peritoneal attachment of this structure should be divided and it should be mobilized to permit careful inspection of its retroperitoneal portion For inspection of the posterior wall of the stomach the greater omentum should be incised in order to allow access to the lesser omental bursa. During the entire exploratory phase of the operation no attempt should be made to repair any defects in the bowel as they are encountered Instead each opening should be temporarily closed with an Allis forceps until the entire problem has been surveyed

Occasionally the surgeon may encounter mesenteric injuries which require attention In general these are of two types The first type is manifested by a hematoma at the junction of the mesentery and the bowel. In this event the serosa of the mesentery should be incised and the mesenteric border of the bowel should be carefully studied for evidence of perforation. Accurate hemostasis in the mesentery must be accomplished without causing unrecognized devascularization of the bowel wall. In the other type the mesentery may have been torn leaving a segment of the bowel denuded If the circulation of the bowel is impaired the segment should be resected. If the denuded portion of the bowel wall measures as much as 2.5 cm. in length the area should be resected, regardless of the color of the bowel involved

TREATMENT OF SPECIFIC INJURIES

Spleen

Following the general exploration of the patient with abdominal trauma, injuries to each of the organs must be considered. In the event of injury to the spleen, it is clear that every lacerated or contused spleen should be removed. To leave a contused spleen behind is to invite the complication of delayed rupture of this organ which may occur at any time up to an interval of 2 years following the injury In a collected series of 46 delayed splenic ruptures McIndoe found that 50 per cent of the ruptures occurred within 3 weeks of the primary injury This correlates well with the experience at the Massachusetts General Hospital (Table 32)

TABLE 32 —Splenic Injuries in 282 Civilian Cases

	No. of Cases	No. of Deaths	Percentage of Mortality
Total number of cases	64	7	10.9
Delayed rupture *	8	1	12.5

* One case each ruptured on 3d, 4th, 6th, 7th, 13th, 18th, 48th, and 145th day after injury

Certain technical features are important in splenectomy (Fig. 570) First the spleen is mobilized from its bed by gentle manual dissection, bringing it forward so that the pedicle can be accurately visualized This is facilitated by packing a large gauze sponge back into the former splenic

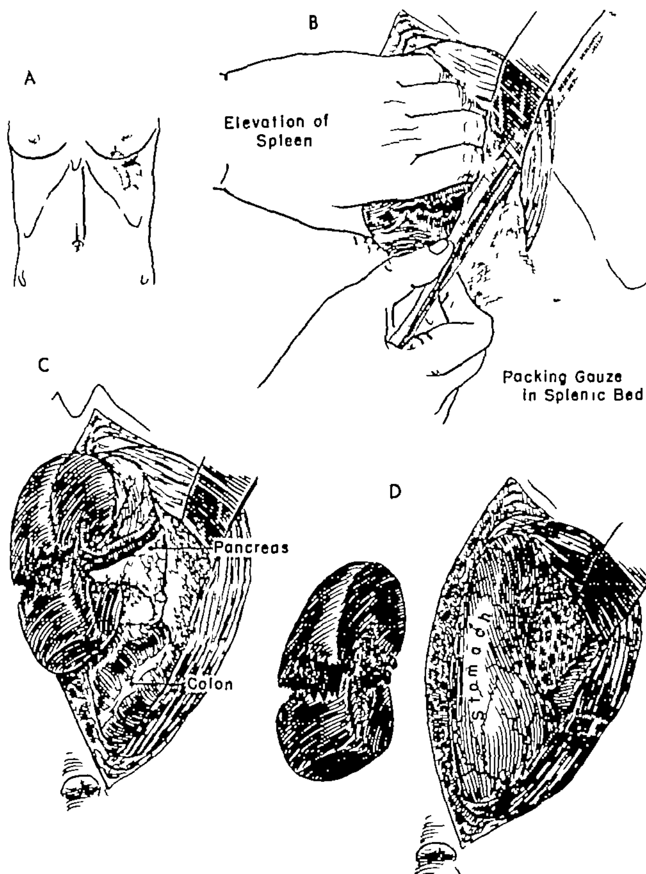


Fig 570 —Splenectomy for lacerated spleen A, left paramedian incision B elevation of spleen by packing gauze against diaphragm. C showing intimate relationship of pancreas stomach, and colon D appearance after individual ligation of splenic vessels.

of the left hand Hemorrhage from the liver may be controlled by gauze packing and manual pressure occasionally this will have to be supplemented by temporary digital occlusion of the vessels of the porta hepatis by inserting a finger into the fora men of Winslow If a rent in the small bowel mesentery is found the hemorrhage should be controlled by digital compression of the involved vessels until the serosa of the mesentery can be incised the hema toma evacuated, and accurate visualization of the severed vessels assured

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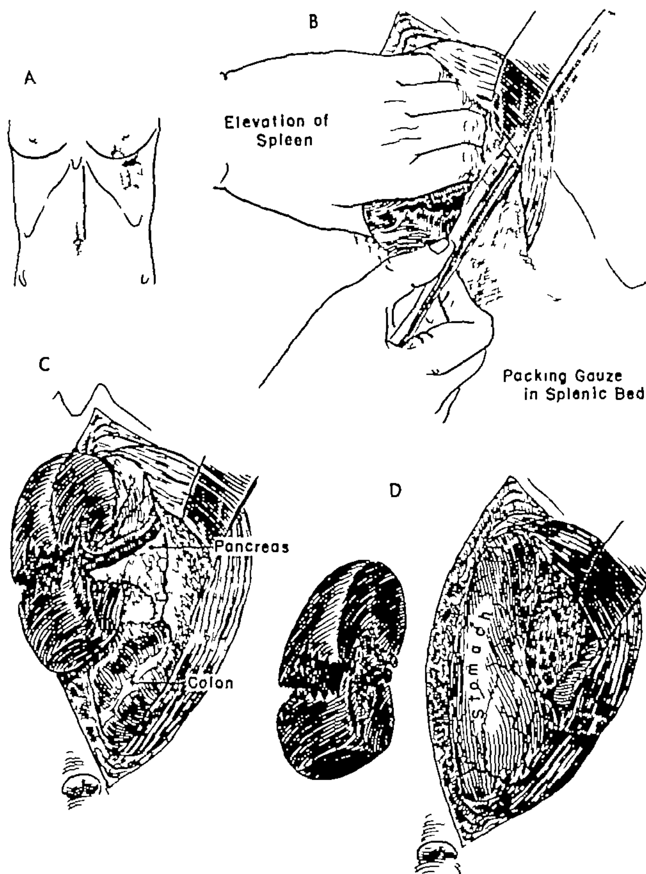


Fig 570 —Splenectomy for lacerated spleen. A, left paramedian incision B elevation of spleen by packing gauze against diaphragm. C showing intimate relationship of pancreas stomach and colon D appearance after individual ligation of splenic vessels

bed during the remainder of the procedure Careful attention must be given to gastric decompression to avoid aspiration during splenectomy and incidental pressure on the stomach and to avoid inadvertent gastric injury during the procedure Unless care is exercised injury to the tail of the pancreas may occur when the splenic pedicle is clamped. The splenic pedicle must be tied accurately with a ligature of No 1 chromic catgut and a suture ligature of No 20 cotton or an equivalent nonabsorbable suture Individual ligation of the splenic artery and vein is preferred

Liver

In dealing with injuries to the liver it must be remembered that many uncomplicated lacerations of this organ recover spontaneously Hemorrhage following hepatic injuries is not frequently a serious problem In 91 per cent of 829 cases of war wounds of the liver reported by Madding Lawrence and Kennedy hemorrhage *had ceased by the time laparotomy was* carried out. However exploration is indicated to control persistent hemorrhage to deal with bile leakage and to allow debridement of necrotic liver tissue In dealing with hepatic injuries the surgeon may employ direct suture drainage of the abdomen alone insertion of packs (absorbable oxidized cellulose or gelatin sponges gauze) or a combination of these methods Generally speaking, the suture method (Fig. 571) is to be preferred where it is applicable and large catgut is suitable for this purpose Use of the absorbable hemostatic sponges is superior to gauze packing which should be reserved for those rare occasions in which disruption of the liver is so severe that no other method will provide hemostosis Occasionally a surgeon may find a massive laceration which is limited to the left lobe of the liver and which may be managed by resection of the entire lobe It is important to remove all devitalized liver tissue since failure to do *so may lead to delayed hemorrhage and* sepsis Foreign bodies embedded in the liver should not be removed unless they are visible and easily accessible Because of potential bile leakage all recognized lacerations of the liver should be widely drained through a separate wound in the right flank.

Wounds of the liver are often complicated by injury to the diaphragm and chest. If the diaphragmatic rent is small and the chest wound slight, many of these cases may be managed by the abdominal route alone However if extensive injury to the diaphragm or chest is present combined abdominal and thoracic incisions should be used or the thoracoabdominal route may be employed. The prognosis in cases of hepatic injury becomes grave whenever there is concomitant injury to other abdominal viscera. This is especially true when associated injuries involve colon stomach duodenum or pancreas

Gallbladder and Bile Ducts

Injuries to the gallbladder and extra*hepatic bile ducts are rare but when they* do occur they should be managed by cholecystectomy or cholecystostomy (depending on the degree of injury) and repair of the ducts with decompression by T tube Such injuries should always be treated with supplemental drains brought out away from the laparotomy wound

Pancreas

Pancreatic injuries are rarely recognized but this complication may be suspected if the serum amylase is elevated If a hematoma is observed overlying the pancreas in the lesser omental bursa, it should be drained through a stab wound in the left upper quadrant. Severe contusion of the tail of the pancreas may be managed by resection of the damaged portion of the organ (Fig 572) If fat necrosis is present the biliary tract should be drained by cholecystostomy All cases of pancreatic injury should be especially studied for associated *injuries to the duodenum*

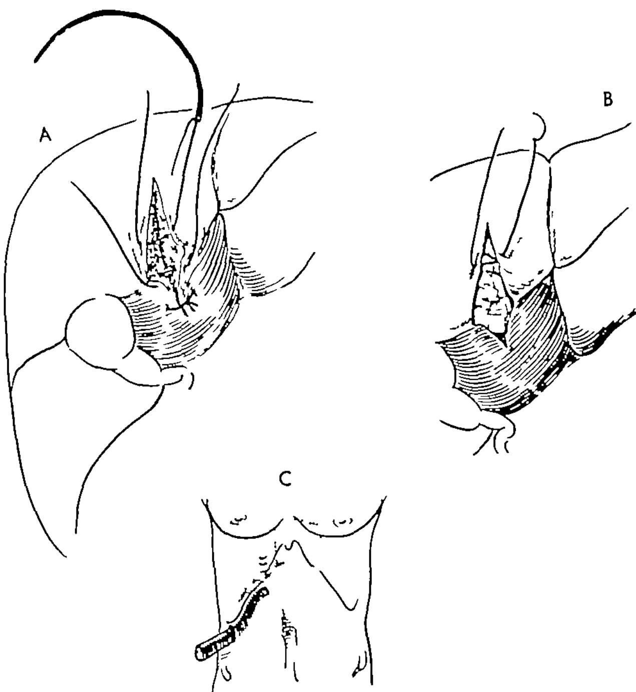


Fig 571 —Repair of lacerated liver A, closure by deep catgut sutures threaded on a blunt needle B closure over Gelfoam® pack C drainage—always instituted

Stomach

Evidence of injury to the stomach demands that this organ be mobilized so that both anterior and posterior walls can be visualized. This should be done by incising the greater omentum external to the gastroepiploic arch Lacerations of the gastric wall should be debrided the defects converted to transverse wounds by means of traction sutures and then closed by a Connell stitch and a second row of sutures approximating serosa to serosa. With respect to the debridement required it should be remembered that wounds inflicted by high velocity missiles damage more tissue than is visible on inspection with the naked eye and adequate debridement must take this principle into account—both in the stomach and in all other areas of injury

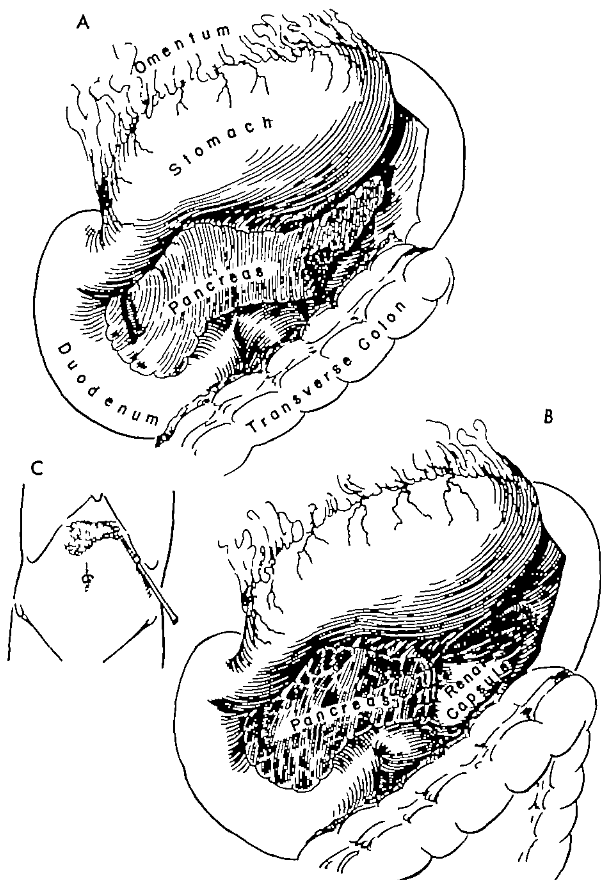


Fig 572.—Repair of contusion of tail of pancreas. A, pancreas exposed through the gastrocolic omentum. B resection of tail C drainage instituted through left flank.

DUODENUM

Duodenal injuries may be hard to iden tify but should be suspected if preliminary x-ray examination reveals gas in the retroperitoneal tissues On direct inspection a retroperitoneal hematoma in the right gut jury exists the lateral peritoneal fold should be incised and the structure should be completely mobilized and inspected Duodenal lacerations should be closed transversely with a two-layer closure (Fig 573) or treated with a sleeve resection and anastomosis and a drain should be

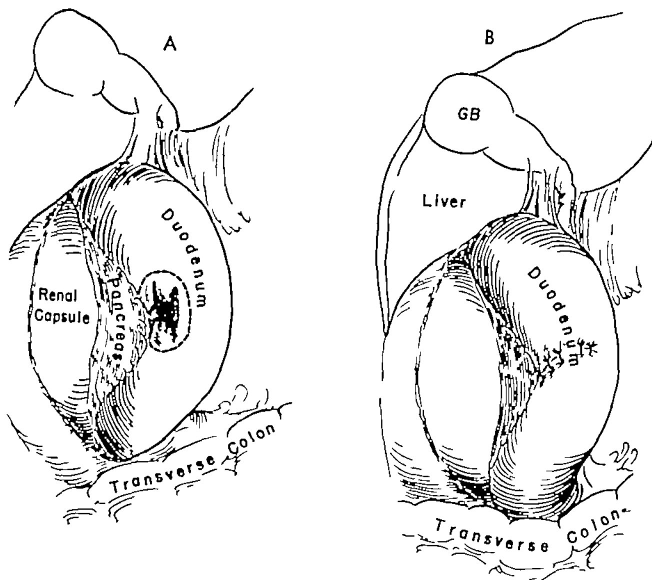


Fig. 573 —Repair of laceration of posterior surface of duodenum. A, mobilization of duodenum by cutting the lateral peritoneal attachments and reflecting the right colon downward. B closure of duodenum by two layers of sutures

ter or dissecting into the transverse mesocolon should alert the surgeon to the possibility of a retroperitoneal duodenal laceration On occasion these hematomas may take on a grayish black appearance presumably because of the admixture of blood and duodenal contents with digestive ferments If any suspicion of duodenal in left in Morison s pouch and led out through a stab wound in the right upper quadrant. Care should be taken to prevent the drain from lying in contact with the suture line since this arrangement favors the development of a duodenal fistula. In duodenal injuries the stomach should be decompressed for 10 days postoperatively either by the

use of a nasogastric tube or by catheter gastrostomy

Intestines

The *management of wounds of the small bowel* requires the exercise of considerable surgical judgment. If the injuries are small not associated with devascularization of the bowel wall and widely separated they should be individually closed with two layers of sutures approximating serosa to serosa avoiding constriction of the lumen of the bowel (Fig 574) On the other hand if the injuries are extensive *compromising the blood supply to the bowel* or multiple within a short segment of the bowel it is better to resect the damaged portion (Fig 575 *A* and *B*) In such circumstances it is good technique to employ the thin bladed Allen clamp leaving the mesenteric border slightly longer than the antimesenteric border and to use an open end to-end anastomosis (Fig 575 C)

Colon

Detailed technical discussion of the management of wounds of the colon requires particularization as to the type of injury location of the wound causative agent and the circumstances under which repair is carried out In general terms simple lacerations as with a knife blade can be sutured without decompression of the bowel if operation is performed soon after injury (Fig 576) When there has been interference with the blood supply or when there is a contusion of tissues surrounding *the perforation, as occurs with a gunshot* wound suture alone is dangerous It is better to exteriorize the area, and this can be accomplished anywhere from the cecum to the lower sigmoid by adequate mobilization of the colon (Fig 577) When the wound is in the lower sigmoid or rectum the wound area cannot be exteriorized and suture must be combined with proximal defunctioning of the bowel preferably by a *transverse colostomy (Fig. 578)*

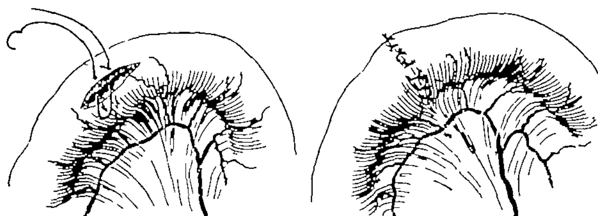


Fig 574 —Closure of minor injuries to small intestines **Left** a smooth defect (a short, sharp incision) which may be closed by two layers of sutures **Right** plastic closure completed by second layer of interrupted sutures

Wounds of the cecum and ascending colon require mobilization of these structures *by incisions of the peritoneum* of the lateral gutter With this maneuver accomplished it is possible to visualize the posterior wall of the bowel and to assess accurately the degree of injury Simple wounds of the cecum may often be handled with a tube cecostomy which is brought out through a gridiron incision in the right lower quadrant (Fig 579)

More extensive wounds of the right colon and hepatic flexure pose a very difficult problem If the time interval between wounding and exploration has been short and peritoneal contamination limited this situation is probably best handled by performing a right colectomy with an open

A

Lines of Resection

B

Mesenteric Defect

Mesenteric and Intestinal Defects

C

End to End Anastomosis Completed

Fig. 575 —Injuries of small intestine treated by resection A resection for avulsion of mesentery B resection for long ragged defects C completion of an open end to-end anastomosis

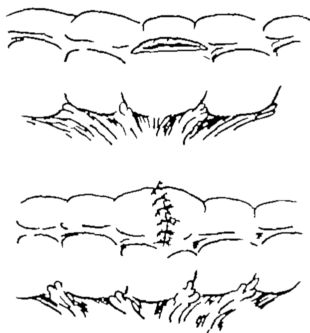
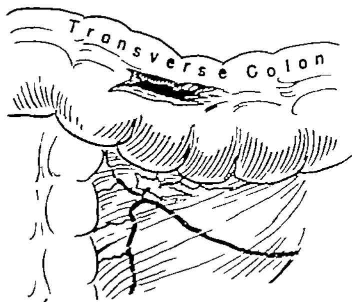


Fig 576 —Repair of short fresh laceration of colon Top stab wound Bottom transverse closure by primary suture

end to-end anastomosis between the termi nal ileum and the transverse colon (Fig 580) On the other hand if the interval be tween wounding and exploration is prolonged and extensive peritoneal soiling has occurred extensive injuries to the right colon may require exteriorization of this structure combined with an end-to-side anastomosis between the ileum and the transverse colon, or with an ileostomy In such a case the right gutter and pelvis of the rectum and mobilization of the rectal segment from the sacrum Some wounds of the rectum will require exposure through the perineum by means of an incision lateral to the coccyx. Careful two-layer closure of all such tears should be accomplished whenever possible and the *peritoneal floor of the left gutter should* be deliberately left open to permit drainage upward into the peritoneal cavity a struc ture much more capable of handling con-



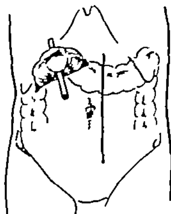


Fig 577 —Repair of extensive ragged defects of colon. *Left* damage to bowel and to mesentery *Right* exteriorization of wound through separate incision.

should be drained. Generally speaking re section of the unprepared bowel should be avoided whenever possible

Wounds of the transverse and descend ing portions of the colon are readily treated by exteriorization of the injured segment and the mobility of the mesentery in these regions usually makes this procedure quite simple Release of the attachments of the flexures and incision of the lateral fold of peritoneum of the descending colon are important points of technique in avoiding tension on the colostomy

Wounds of the lower sigmoid and rec tum are more difficult to handle Many of these wounds can be exposed from above by incision of the peritoneal attachments tamination and sepsis than the retroperi toneal space A defunctioning proximal colostomy is required to protect all such repairs to the sigmoid and rectum and this is usually most conveniently placed in the transverse colon (Fig 578) In order to insure complete diversion of the fecal stream the colon is divided between clamps and the two ends are separated by a narrow interval of the abdominal wall. The clamps are removed from both colostomy stomas on the first postoperative day thus releasing all tension on the suture lines As a final step if the operation has been entirely through the abdomen the patient is turned into the lateral decubitus and the retrorectal space is drained by in-

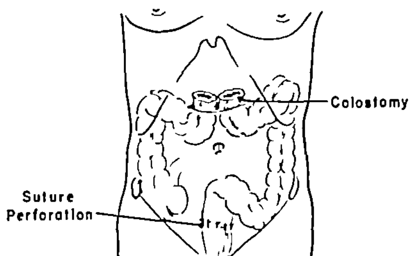


Fig 578 —Repair of wound of low sigmoid or rectum by a completely defunctioning transverse colostomy made after suture of the sigmoid laceration

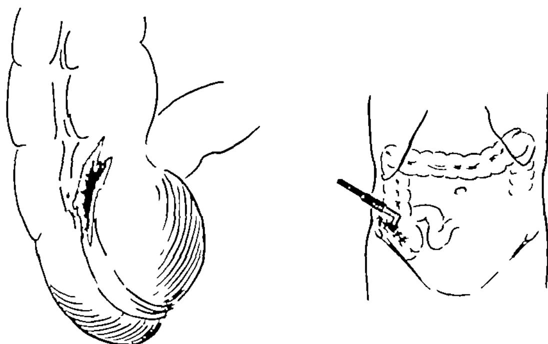


Fig. 579 —Repair of single laceration of cecum. **Left** laceration **Right** closure of laceration around a large rubber tube

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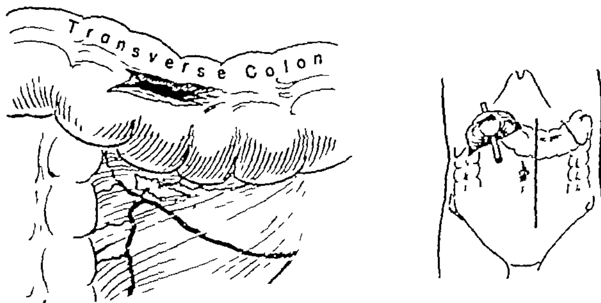


Fig 577 —Repair of extensive ragged defects of colon. Left damage to bowel and to mesentery Right exteriorization of wound through separate incision

ton on the skin Accurate healing function of the sphincter and any required dilation of the anal ring should be prerequisites to closure of the colostomy

Kidney Ureter Bladder and Urethra

Wounds of the kidney encountered in civilian life are usually contusions and should be treated conservatively Nephrectomy is rarely indicated it is reserved for cases of severe disruption of the kidney associated with marked hemorrhage or sepsis (Table 33) In military experience severe lacerations of the kidney or the

TABLE 33 —Renal Injuries in 282 Civilian Cases

Total number of cases	115
Nephrectomy performed (cases)	5 (2 deaths)
Nephrectomy not performed (cases)	110 (1 death)
Deaths due to renal injuries	3
Mortality (115 cases)	2 6%

renal vessels are relatively more frequent Thus in casualties treated by the Second Auxiliary Group in World War II nephrectomy was required in 28 1 per cent of cases with renal injury

If nephrectomy is contemplated either an oblique flank incision or the thoraco-abdominal approach may be employed The advantage of better visualization and control of the renal pedicle afforded by the latter approach is somewhat offset by the increased hazard of opening the chest cavity in patients sustaining multiple injuries The ureter should be doubly ligated with one of the ties being a suture ligature of nonabsorbable material Nephrectomy wounds should be drained since urinary drainage secondary hemorrhage sepsis and urinary fistula may occur as complications

Injuries which may cause ureteral injury require exposure and visualization of this structure lest serious retroperitoneal urinary extravasation occur While trivial ureteral injuries may be simply sutured more extensive injuries require resection of the damaged portion and restoration of continuity High ureteral injuries may be repaired by end to-end anastomosis low injuries are best handled by re implantation into the bladder In either case a T tube may be employed as a stint with the side arm of the tube being brought out through a stab wound away from the ureteral anastomosis Drainage of the retroperitoneal space is mandatory

Rupture of the bladder may be suspected when insertion of a catheter fails to produce appreciable amounts of urine This observation should be checked by instilling measured amounts of saline and testing for the return of the saline through the catheter An alternate method is the injection of sodium iodide or Diodrast® and x ray examination In civilian injuries rupture of the bladder is usually associated with fractures of the pelvis cases occuring in military practice are associated with a high incidence of injuries to the intraperitoneal viscera. Wounds of the bladder are treated by suture and suprapubic cystostomy It is sometimes possible to catheterize the urethra through the bladder at other times primary repair of the bladder neck as described by Leadbetter should be done

POSTOPERATIVE CARE

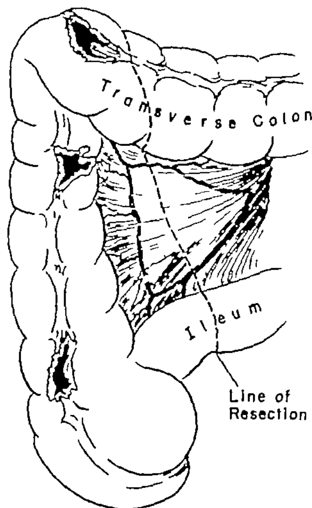
The postoperative management of patients with abdominal injuries requires meticulous care Associated injuries must not be neglected Continued use of oxygen antibiotics gastrointestinal decompression and whole blood as required should be the universal rule Parenteral fluids and electrolytes should be administered as needed Except in the presence of severe cardiovascular disease or marked oliguria it is usually adequate to plan on a daily quota of 2 000 cc of 5 per cent dextrose in water 500 cc of 5 per cent dextrose in saline and 40 milliequivalents of potassium Additional increments of water sodium chloride and potassium are added to

cision through the tough fascia propria of the rectum which attaches to the coccyx. Careful attention to this detail is essential because drainage to the hollow of the sacrum must be attained if this maneuver is to be effective Drains should not be placed near the suture lines Removal of the coccyx in these circumstances is unnecessary and may be followed by osteomyelitis of the sacrum

Some procedures in the surgery of wounds of the colon deserve special condemnation—namely inadequate mobilization of the bowel placement of the colostomy in the laparotomy incision and the use of the Mikulicz type of resection in cases where the patient s condition will permit employment of the better procedures outlined above

Anal Sphincter

Lacerations of the anal sphincter require a proximal defunctioning colostomy Local repair should be accomplished by mobilizing the sphincter through a semicircular incision placed well away from the mucocutaneous junction. Edges of the defect should be accurately approximated by catgut sutures and tension may be kept from the suture line by means of wire mattress sutures placed through the sphincter away from the injured area carried across the defect and tied over a but



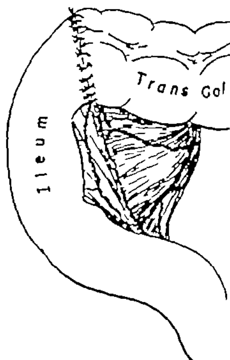


Fig 580 —Repair of severe injuries of right colon Left mobilization and resection Right end-to-end ileocolostomy

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cover all extrarenal losses as from gastric suction, fistulas or other drainage tubes Frequent determinations of the hemoglobin and of blood electrolytes are made during the first few postoperative days to insure accurate replacement therapy When peri staltic activity is restored as judged by the passage of flatus the nasogastric tube is removed and gradual resumption of oral nutrition is begun. Drains are mobilized on the seventh postoperative day and removed a day or two later if no excessive exudate is observed Sutures are removed no earlier than the tenth postoperative day and they may be left much longer if the circum stances of nutrition, distention, or local wound healing require such delay

Common complications encountered af ter repair of abdominal injuries include peritonitis intra abdominal abscess small bowel obstruction wound abscesses and wound dehiscence Abscesses most com monly occur in the wound the pelvis and the subphrenic space They may also be formed in the peritoneal cavity between adjacent loops of bowel or mesentery and the omentum Wound abscesses should be treated by opening the involved area widely Abscesses within the peritoneal cavity should be drained by an incision through the abdominal wall directly over the presenting mass while pelvic abscesses may be drained through the vagina or rec tum Subphrenic abscesses are drained by resecting the twelfth rib on the affected side and evacuating the pus through the rib bed. Cigarette drains should be left in all abscess cavities and gradually with drawn as the cavities are obliterated. Wound dehiscence should be repaired by closely placed wire sutures which extend through all layers of the abdominal wall. Small-bowel obstruction may be tempo rarily decompressed by the use of long in testinal tubes but will often require ly sis of adhesions or the use of bypassing anastomoses Thromboembolism is always a threat particularly among older civilian patients and prophylaxis should include elastic bandaging of the legs active exer cises and early ambulation. Established thrombophlebitis is definitely treated by superficial femoral vein interruption com bined with the administration of appropri ate anticoagulants when there is no special reason to fear intra abdominal or gastro intestinal hemorrhage

World War II experience clearly demon strated that the mortality rate of casualties sustaining abdominal injuries is improved when surgery is performed in the forward areas and evacuation is delayed until con valescence is established This principle of early definitive surgery was further ex tended during the Korean War However late complications fistulas and colostomy closures are properly handled in evacua tion hospitals or in the interior zone

TABLE 34 —ANALYSIS OF DEATHS PENETRATING INJURIES

Case No.	Age Sex	Date	Injury	Treatment
1	18 M.	9/28/34	Gunshot wound of abdomen 5 weeks before admission. Four teen perforations of intestine su tured at outside hospital. Peri tonitis and draining laparotomy wound on admission bullet op posite vertebra S4	Laparotomy 8 days after admis sion. Peritonitis. Patient died in ether convulsion on operating ta ble Death probably due to perfo ration missed at initial explora tion.
2	15 M.	6/26/35	Diving struck abdomen on bot tom of pool 1 hour before admis sion. Extensive laceration of ab dominal wall with evisceration of small bowel.	Laparotomy 1 hour after admis sion. Bowel replaced abdominal wall repaired. Death from peritoni tis on 3d postoperative day *

Death would probably have been prevented had antibiotics been available

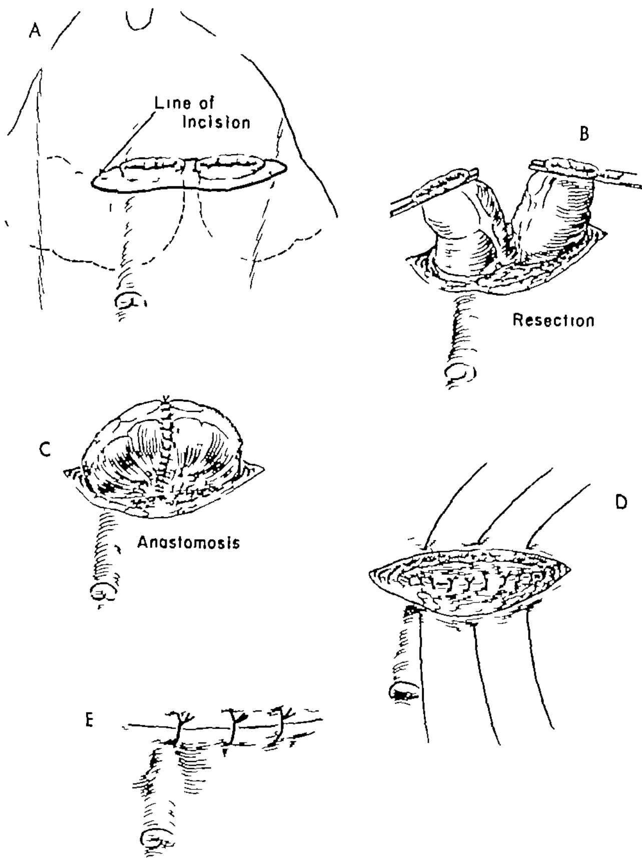


Fig. 581 —Closure of colostomy A mobilization of the colostomy B resection of the edematous stomas C open end-to-end two-layer anastomosis D preparation for delayed primary closure subcutaneous tissue and fat held open by gauze pack for 48 hours E appearance after delayed primary closure

Colostomy Closure

No set time can be affixed for the closure of a defunctioning colostomy In general one should wait until the edema and the inflammatory reaction in the wound have subsided. In most cases a delay of 2–3 weeks will be adequate but under military conditions a longer period may be more desirable It is wise to demonstrate the integrity of the defunctioned bowel by barium enema before closure of the colostomy is performed Although extraperitoneal closure of colostomies and Mikulicz resection with crushing of the spur have been recommended by some modern techniques make intraperitoneal closure (Fig 581) much safer and far more satisfactory Stronger wound repair and better function of the anastomosed bowel are to be expected from intraperitoneal closure It is wise to prepare the bowel preoperatively by administration of Sulfathalidine® or Sulfasuxidine® in dosages of 8 0 Gm. daily for 5 days The colostomy stomas and intervening skin are excised and discarded and an open end to-end anastomosis is performed. The repaired bowel is then dropped back into the peritoneal cavity and peritoneum and deep fascia are sutured in separate layers Healing of these wounds without sepsis is promoted if the procedure of

TABLE 35 —Analysis of Deaths Blunt Injuries

Case No.	Age Sex	Date	Injury	Treatment	Comment
1	81 M	4/16/30	Blow by circular saw Contusion of abdomen.	Exploratory laparotomy Retroperitoneal hematoma.	Died in shock 8 hours after operation. Poor heart contributed to death.
2	55 M	4/8/31	Crushed by timber Fractures of both pubes and transverse process L2; separation of left S-1 joint.	Suprapubic cystostomy for ruptured bladder	Died in shock 2d post operative day
3	45 F	6/27/32	Struck by auto Hematuria; shock.	Splenectomy for ruptured spleen 3¼ hours after injury	Died on 9th postoperative day Peritonitis?
4	5 M.	7/16/32	Fall. Gross hematuria; anemia	*Left nephrectomy for* ruptured kidney 2 days after injury Developed uremia. Right kidney explored 5 days after injury; found small, cystic and functionless.	Died in uremia 11 days after injury Error in judgment.
5	26 M.	12/15/33	Crushed by auto Mild concussion; microscopic hematuria.	Laparotomy 4½ hours after injury Two serosed tears of colon sutured. Ruptured jejunum sutured.	Died of peritonitis on 4th postoperative day
6	12 M	7/9/34	Fell from bicycle 27 hours before admission	Laparotomy promptly after admission. Sutured 2 lacerations of jejunum. Peritonitis	Died on 1st postoperative day Death due to failure to appreciate severity of injury
7	46 F	7/16/34	Abdomen crushed by auto.	Laparotomy 2¼ hours after injury Serosal tear of colon sutured. Massive retroperitoneal hematoma	Died of shock on operating table

(Continued)

TABLE 35 —*Continued*

Case No.	Age Sex	Date	Injury	Treatment	Comment
8	19 M	7/29/34	Crushed by auto Unconscious.	Laparotomy 2½ hours after injury Spleen ruptured with 4 inch rent in diaphragm Splenectomy	Died immediately after operation Shock pneumothorax
9	? F	5/17/35	Fell 3 stories Unconscious; shock; compound fracture of both bones of left forearm and of right ulna	Laparotomy 2¼ hours after injury Extensive laceration of right lobe of liver; packed with towel and several large gauze sponges.	Died on day of operation Shock and head injury
10	3 F	5/24/36	Crushed by auto wheel	Laparotomy 36 hours after injury Three-inch laceration of liver coated with fibrin; hemorrhage into transverse mesocolon.	Congenital lues just recovered from measles and pneumonia. Died on 18th postoperative day from pneumonia, empyema, and infarction of liver
11	73 F	8/22/36	Crushed by bus Fractures of both humeri pubis, spine right knee right ankle microscopic hematuria.	Supportive Lapsed into coma and died in 1 hour	Death due to severity of injury
12	54	2/2/38	Struck by falling iron 8 hours before admission Irrational; shock; fractures of transverse processes L1–L4 inclusive of both ilia, and of pubis.	Supportive only	Died 4 days after injury Autopsy showed rupture of spleen contusion of right kidney laceration of left psoas muscle Death ascribed to failure to do laparotomy
13	25 M.	9/19/39	Automobile crushed by train. Fractures of humerus elbow femur fibula, tibia, and multiple ribs all on left side; subcutaneous emphysema.	Supportive. Never responded to shock treatment. Died 3 hours after injury	Probably had lacerations of lung and liver Death not preventable
14	33 M.	12/19/39	Crush to head chest and abdomen; severe concussion; shock; gross hematuria; fractures of right clavicle 3d through 7th ribs right left 2d rib; fracture of mandible.	Laparotomy 2 days after injury Hemoperitoneum source not identified.	Died on 3d postoperative day Probably had puncture of lung Might have been saved by thoracotomy prior to laparotomy
15	38 M	3/6/40	Knocked from moving car Unconscious; shock; fractures of all left ribs left knee; ecchymosis entire left abdomen.	None	Died in shock 6 minutes after entry
16	50 M.	4/5/50	Crush to abdomen. Shock conscious.	Supportive only	Recovered from shock and then gradually declined Died on 5th day from bile peritonitis? Should have had laparotomy

(*Continued*)

TABLE 35 —*Continued*

Case No.	Age Sex	Date	Injury	Treatment	Comment
17	55	8/1/40	Struck by auto. Unconscious shock; right lower quadrant mass growing in size; fractures of right humerus right forearm, pelvis left tibia.	Suprapubic cystostomy Local anesthesia 5 hours after injury	Died in shock 10 hours after injury Death due to severity of injuries.
18	74 M	9/3/40	Struck by auto. Unconscious; shock; basal skull fracture laceration of brain; rupture right kidney; large mass right flank.	Supportive.	Moribund on admission and died shortly thereafter Death due to severity of injuries.
19	?	8/19/41	Struck by car Unconscious; shock; gross blood per catheter; compound fractures of both femurs; fracture of elbow and pelvis. Rupture of bladder?	Supportive	Died in shock less than 1 hour after entry Death due to severity of injuries.
20	28 F	3/12/42	Struck by car Conscious; shock; gross hematuria; left Colles fracture.	Right nephrectomy for laceration of kidney 4 hours after injury	Died 10 days postoperatively from anemia uremia, pulmonary edema. Reason for downhill course not clear
21	65 M	7/6/42	Fell 4 feet 4 days before entry Signs of established peritonitis	Supportive	Died 12 hours after entry Autopsy showed ruptured sigmoid and peritonitis. Death due to patient's delay
22	4 M.	9/10/42	Struck by truck. Disoriented; shock; severe concussion. Brain laceration?	Laparotomy 6 hours after injury Multiple severe contusions and lacerations of liver rupture of spleen. Splenectomy	Died 11 hours after injury Death due to severity of injury
23	42 M.	11/13/45	Fell 60 feet. Unconscious; shock; gross hematuria; hemothorax; multiple fractures of ribs and pelvis.	Exploratory laparotomy 24 hours after injury Rupture of right kidney; large retroperitoneal hematoma	Adrenal failure. Died on 7th postoperative day Autopsy showed rupture of right kidney with hematoma, adrenocortical necrosis slight fat embolism. Death ascribed to severity of injury but might have been preventable with cortisone.
24	51 M.	12/7/45	Fell 50 feet. Unconscious; shock; gross blood per catheter Contusion of kidney?	Supportive	Died 2½ hours after injury Death apparently due to the severe head injury
25	56 M.	6/24/48	Fell on stairs 7 days before entry Delayed rupture of spleen 12 hours before entry	Laparotomy and splenectomy shortly after admission Ligature slipped from splenic pedicle 1 hour after operation. Patient re-explored died in shock on operating table	Death due to technical error

(*Continued*)

TABLE 35 —*Continued*

Case No.	Age Sex	Date	Injury	Treatment	Comment
26	32 M	2/8/50	Crushed between rail road car and ramp Conscious; no fractures.	Laparotomy and splenectomy for ruptured spleen 3 hours after injury Inadequate abdominal exploration	Febrile course falling hemoglobin distention jaundice Died on 8th postoperative day Associated injuries were probably overlooked
27	2 M.	6/5/52	Struck by automobile Unconscious; fracture of left 7th rib contusion left kidney	Laparotomy 4 hours after injury Ruptured spleen removed and laceration of stomach repaired	Died 12 hours after injury Death due to severity of injury
28	9 F	8/14/52	Crushed by truck. Unconscious; shock; fractures of right tibia and fibula	Thoracoabdominal exploration and suture of liver 2 hours after injury (right lobe of liver nearly amputated)	Died 12 hours after injury Death due to severity of injury

delayed closure of fat and skin as recommended by Coller and Volk, is used

In summary in the series of 282 abdominal injuries treated at the Massachusetts General Hospital during the period 1930–53 16 3 per cent of the injuries were caused by penetrating injuries and 83 7 per cent by blunt trauma. The mortality rate for penetrating injuries was 4 3 per cent for blunt traumas 11 9 per cent. An analysis of all deaths in this series is presented in Tables 34–36 The importance of a time lag between wounding and treatment and of multiplicity of injuries as factors increasing the mortality rate is clearly emphasized by this analysis

TABLE 36 —SUMMARY OF CAUSES OF DEATH IN 28 CASES OF BLUNT INJURIES TO ABDOMEN

1 Multiplicity and severity of injuries		12
2 Inadequate shock treatment		4
3. Technical errors:		3
Inadequate exploration	2	
Inaccurate ligature	1	
4 Laparotomy withheld		2
5. Error in judgment		2
Removal of only functioning kidney	1	
Failure to do thoracotomy	1	
6. Peritonitis or pneumonia (preventable with antibiotics)		2
7 Delay in treatment*		2
8. Unknown		1
Total		28

* In both cases, delay occurred before patient came to the hospital.

It should be noted that a negative abdominal exploration is safer than a missed diagnosis of visceral injury in cases of blunt abdominal trauma Also strict attention must be paid to the details of pre and postoperative care

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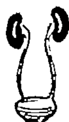
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38 

Injuries to the Genitourinary Tract

In all cases of extensive multiple contusions or puncture wounds of the body particularly those accompanied by hematuria and by fractures of the ribs or bony pelvis the possibility of injuries to the genitourinary tract should be kept in mind Over sight or inadequate treatment of these injuries may prolong the morbidity or even result in unnecessary mortality The amount of blood in the urine is not a reliable criterion of the extent of injury relatively clear urine may be passed by an individual with a rupture of the bladder and bloody urine may come from a simple contusion of the kidney If physical findings are consistent with trauma to the genitourinary tract certain investigative measures are indicated The physical signs diagnostic measures and methods of repair for this type of injury are outlined in this chapter

KIDNEY

Mechanism of Injury

Although the kidney normally is pretty well protected by the thoracic cage it is quite vulnerable when a rib is fractured The kidney may be punctured by a missile or by a splinter from a broken rib or it may be acutely angulated and split when bent over the lower rib by the application of external force through the abdomen Large solitary kidneys or hydronephrotic kidneys are particularly susceptible to injury from relatively slight blows delivered from the front side or back

The nature of the injury to the kidney may vary from simple contusion to a small crack in the lining of the pelvis to complete separation of a portion of the parenchyma. The usual type of trauma in the patient who survives initial injury is characterized by a split in the parenchyma with extravasation of blood and urine throughout the perirenal fat Penetrating wounds may perforate not only the kidney but also any of the many viscera which are adjacent to it at this horizontal plane

Diagnosis

In cases of suspected injury to the kidney the physical findings and urinalysis should be interpreted carefully If there is a penetrating wound the wound of exit should be sought in an effort to visualize concomitant injury to the lung stomach bowel liver or spleen Fluid draining from an open wound in the flank may come from

the kidney bowel or pleural or peritoneal cavities This drainage may be identified as urine if it assumes a bluish color following the intravenous injection of 5 cc of indigo carmine Serous exudate from the pleura or peritoneum is not discolored with this test Although localized flank pain is a cardinal symptom of ruptured kidney tenderness in this area may also be associated with a fractured rib or contused muscle In an early case of ruptured kidney fullness in the flank is seldom observed If the ureter is obstructed with blood clots or if the renal pelvis itself has been split there may be only a few red cells in the bladder urine A state of shock, with pain in the upper abdomen may indicate a ruptured spleen as well as a ruptured kidney

To confirm the diagnosis of a ruptured kidney therefore x ray films are necessary A plain plate of the abdomen is of some help it will reveal foreign bodies and the renal outlines If there has been extensive extravasation of blood and urine around the kidney the renal outline as well as the psoas shadow will be obliterated A pyelogram of course is the best indication of the extent of renal damage The selection of the type of pyelogram however is a controversial subject Some urologists advocate intravenous pyelograms others prefer cystoscopy and retrograde pyelograms. Those who favor the intravenous route point out that by this method the risk of introducing infection into the collection of blood and urine lying outside a ruptured kidney is avoided They are quite right, but pyelograms obtained by introducing dye into the kidney pelvis through a ureteral catheter are so far superior to those obtained by intravenous pyelography (Fig 582) that the risk of infection is justified The poor function of a ruptured kidney usually results in an output of dye inadequate to outline satisfactorily the renal pelvis the calyces and the amount of extravasated urine If furthermore infection is introduced into the collection of urine and blood in the perirenal space it may be drained surgically before irreparable damage has been done Before attempting an intravenous pyelogram inquiries should be directed to the patient concerning food sensitivities hay fever asthma or other allergies Such conditions contraindicate of course the intravenous administration

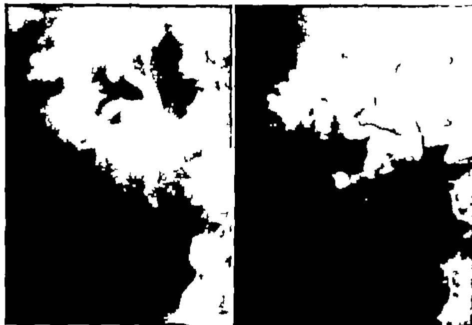


Fig 582.—Comparison of pyelograms of a ruptured kidney *Left* an intravenous pyelogram. *Right* a retrograde pyelogram. Much better visualization of the extent of extravasation is obtained by the retrograde pyelogram.

of any of the dyes used for pyelograms Allergy on the other hand does not interfere with administration of dye through a ureteral catheter for a retrograde pyelogram. A history of allergy is of more significance than the results of the sensitivity test where diluted dye is dropped onto the conjunctiva The only severe reactions seen at the Massachusetts General Hospital have been in individuals who gave negative reactions to sensitivity tests but who had a previously undetected history of asthma.

Treatment

Treatment of a ruptured kidney depends on the extent of the trauma and the possibility of injury to other organs Before any surgery is performed the presence of two kidneys should be demonstrated Congenital absence of one kidney is too common to justify the assumption that a badly traumatized kidney may be removed with impunity

Except in cases of threatened exsanguination from a torn renal pedicle surgical measures should be deferred until the patient has been brought out of his condition of shock. The actual management of an injured kidney will depend on the individual circumstances A simple contusion of the kidney with bloody urine but with no evidence of leakage of urine into the perirenal tissues will usually quiet down spontaneously without surgical interference.

The selection of the most appropriate incision will be determined by the type of injury If the injury is confined to the kidney the usual extraperitoneal flank incision is satisfactory If on the other hand there is also injury to the lung or spleen the surgeon will gain excellent exposure with a thoracoabdominal approach removing the tenth rib and using endotracheal anesthesia Concomitant injury to the abdominal viscera merits of course a transperitoneal approach But with this incision the kidney lies at the bottom of a deep hole and this approach is not recommended unless it is absolutely necessary

A penetrating wound of the kidney which drains blood and urine to the skin should of course be explored promptly After debriding the wound thoroughly the surgeon should attempt to acquire hemostasis in the kidney with the aid of pieces of muscle or fat held against the bleeding surface by mattress sutures At this time the surgeon also should look carefully for foreign bodies because such items left in the region of the kidney may be responsible for an overwhelming sepsis which will necessitate a nephrectomy 2 or 3 weeks after the original injury Particularly with penetrating wounds adequate drainage of the operative field is of paramount importance

Nephrectomy of course is indicated in cases of uncontrolled bleeding and of massive destruction of the renal parenchyma When the surgeon encounters a solitary kidney which has been shattered into a number of pieces by external trauma, he will lose nothing by attempting to hold the fragments of kidney together in a basket of ribbon catgut draining the renal pelvis with a nephrostomy tube and inserting numerous cigarette wicks to drain the perirenal tissues The inexperienced surgeon should be cautioned against the removal of a kidney which is salvageable When he explores a suspected ruptured kidney he is quite likely to mistake the bloody perirenal fat for a macerated kidney and to carry out a nephrectomy too hastily If he will exercise restraint he may discover that he is dealing simply with a perirenal blood clot which is coming from a crack in the kidney at the very bottom of the wound

Authorities differ in their management of the type of ruptured kidney characterized by moderate hematuria some enlargement in the renal outline moderate deformity of the calyceal outlines and x ray evidence of leakage of urine into the perirenal tissues One group advocates conservative care pointing out that these patients usually get well without surgery This may be true but the patient will have a better kidney in later years if the collec

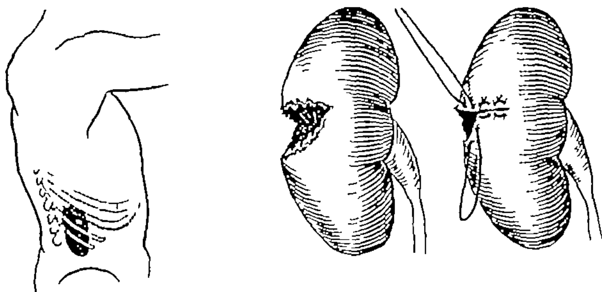


Fig 583 —Closure of a laceration of a kidney by means of mattress sutures

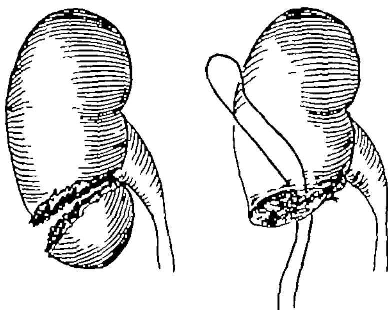


Fig 584 —Method of placing mattress sutures for the control of bleeding where one pole of a kidney has been broken off

tion of blood and urine in the perirenal tissues is drained surgically Unless this is done the kidney is quite likely to become atrophied as the result of interference with its blood supply by the organization of the perirenal blood clot Or the kidney may become hydronephrotic as the result of constriction of the ureter by scar tissue

Accordingly under these circumstances it is recommended that ruptured kidneys be explored through a flank incision 5 or 6 days after injury and given a chance for survival By waiting during this interval the surgeon will find that the bleeding vessels are pretty well thrombosed and that the clot will peel off the kidney easily Definitive surgery at this time is much more satisfactory than when carried out earlier If operation is attempted within a day or two of the injury the surgeon is

troubled with excessive bleeding and abnormal softness of the tissues At the appropriate time cracks in the kidney may be closed with mattress sutures (Fig 583) Bleeding tendencies from open ends of the kidney are controlled with through and through mattress sutures of catgut (Fig 584)

In cases where a portion of the kidney has been cracked off the use of a nephrostomy tube to drain the pelvis of the remaining stump of the kidney is not recommended since a nephrostomy tube affords pathway for the introduction of bacteria into the kidney These organisms may prove very difficult to eliminate before they succeed in damaging the kidney or creating the framework for a renal stone In the exceptional case where a tube is indicated extra precautions should be taken to maintain a sterile drainage system and the nephrostomy tube should be removed at the end of 8 or 10 days when a sinus will have formed.

After the repair of such damaged kidneys, follow up studies are mandatory An intravenous pyelogram should be made at the end of 3 months to eliminate the possibility of urinary calculi or hydronephrosis which might require more definitive surgery Infection should be eradicated

URETER

Diagnosis

Without a penetrating wound traumatic injuries to the ureter are not common When they do occur with a penetrating wound they manifest themselves fairly promptly by the drainage of thin fluid from the wound of entry The identity of this fluid is established if it assumes a blue color following the intravenous injection of indigo carmine But the ureter may be traumatized without an open break in the skin. Under these circumstances the injury usually is not recognized until the patient develops a spontaneous fistula in his flank or upper abdominal wall

Positive diagnosis of a ruptured ureter of course can be made only by a ureterogram Sometimes an intravenous pyelogram will be adequate this may show moderate dilatation of the kidney pelvis and upper ureter At the lower end of this dilated ureter a pool of dye may be seen lying outside the urinary tract Partial filling of the distal ureter would not be expected if present it would suggest that the ureter had not been severed completely and that urine was leaking through a short split in the ureteral wall

Treatment

In the management of ureteral injuries the surgeon should be guided by one thought—the preservation of the kidney above the damaged ureter Nephrectomy seldom is necessary even though it might be the simplest solution to a perplexing situation A wiser procedure would be to insert a nephrostomy tube for temporary diversion of urine and then to carry out an appropriate reparative procedure at a later date

Despite its small size the ureter lends itself well to reconstructive procedures Occasionally with antibiotics and drainage of the periureteral region a small opening in the ureter will heal spontaneously In such a case it usually is desirable to pass a ureteral catheter through the bladder up the ureter past the defect, as far as the kidney pelvis This catheter is prevented from slipping out by being lashed with silk thread to a small Foley catheter which is passed down the urethra, beside the ureteral catheter into the bladder This drainage system is left in place for 4 or 5 days at the end of which time the ureteral fistula should be healed

If the ureter has been severed completely it is best repaired by a meticulous end to-end anastomosis (Fig 585) as soon as the local infection and slough have been cleared up The natural elasticity of the ureter permits the closing of a gap of 2–3 cm in those cases where a segment of the ureter may have been lost To approximate the ends of a ureter the edges should be

everted with interrupted 5-0 chromic cat gut sutures A ureteral splint is desirable For this the upper arm of a small T tube may be used with the stem being brought out through a small nick in the ureteral wall below the line of anastomosis. Better still is a piece of polyethylene tubing brought from the kidney pelvis down the splint in 8 days On the ninth day an anterograde pyelogram is done by injecting 50 per cent Hypaque® through the nephrostomy tube into the renal pelvis and down the ureter If the passage is unobstructed, the nephrostomy tube should be clamped for 24 hours If there is no evidence of back pressure the tube should be removed on

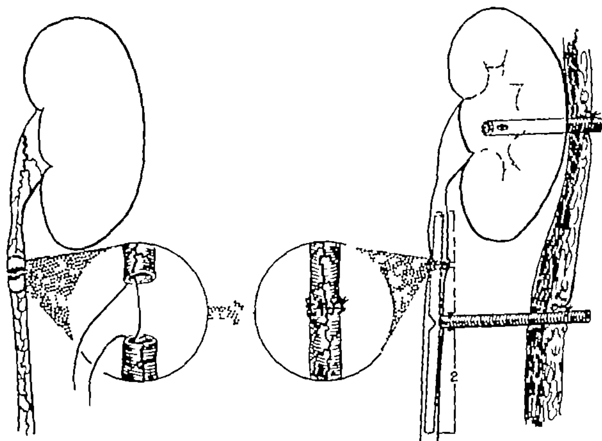


Fig 585 —Repair of a severed ureter by means of interrupted 5-0 atraumatic catgut sutures to evert the edges of the ureter and a T tube and nephrostomy tube to divert temporarily the urine from the repaired ureter Each arm of the T tube measures about 2 inches

ureter through the anastomosis and out to the skin through an opening in the ureter below the suture line To prevent angulation of the ureter at the level where the tube leaves the ureter the surgeon should make sure that he has left plenty of slack in the splint between the skin and ureter With either the T-tube or the straight tube splint a nephrostomy tube should be placed in the kidney above

In the postoperative management of cases of severed ureters the cigarette drains are removed in 6 days and the ureteral the tenth day with the expectation that the ureteral sinus will close promptly

Where a sizable longitudinal segment of the wall of the ureter has been lost but the ureter is still intact there may be use for the Davis intubated ureterotomy In this procedure a No 12 or No 14 F plastic or rubber tube is run longitudinally between the ends of the normal ureter and directly over the narrow isthmus joining the ends. This tube and a nephrostomy tube above, are left in place from 4 to 6 weeks by which time the mucosa and muscularis of

; ureter will have regenerated to form a w ureter In principle the operation sounds reasonable but the results at the Massachusetts General Hospital have not been spectacular

Regardless of the method used the surgeon should obtain an intravenous pyelogram 3 months after the operation to make sure that ureteral strictures or stones have not marred the results of his handwork.

BLADDER

Mechanism of Injury

Traumatic rupture of the urinary bladder with extravasation of urine into the perivesical tissues or into the peritoneal cavity must always be considered in cases of injury to the lower abdomen and a distended bladder is much more susceptible to injury than an empty bladder which lies behind the pubic bone Injury may result from a direct blow to the lower abdomen or from perforation by a missile or spicule of bone broken loose from a fracture of the bony pelvis. Frequently this type of rupture is complicated by similar injuries to neighboring organs like the rectum or vagina.

Symptoms

Although symptoms of a ruptured bladder usually develop immediately after the accident, they may be delayed for as long as a week. Ordinarily leakage of urine from the bladder produces severe localized pain in the lower abdomen If the break communicates with the peritoneal cavity the patient will also suffer nausea and vomiting. Usually he will be unable to void at times he may pass small amounts of bloody urine In one case at the Massachusetts General Hospital the initial symptoms subsided promptly and the patient got along comfortably for 1 week At the end of that time however the severe suprapubic pain recurred and the patient observed a trickle of blood from the urethra. Laparotomy demonstrated a rent in the bladder wall 5 cm long which had been plugged temporarily by a wad of omentum The patient with a history of trauma to the lower abdomen and of pain in the same region merits careful observation for a long period

The amount of blood in the urine is not a reliable index of the severity of trauma to the bladder One patient with a large tear in the bladder may pass relatively clear urine while another with an intact bladder may have urine loaded with blood cells which are coming from injury to other parts of the genitourinary tract such as from a previously unsuspected neoplasm of the bladder or from a simple contusion

Diagnosis

A positive diagnosis of ruptured bladder can seldom be made without x ray examination including a cystogram While it is possible in cases without surgical shock to get a satisfactory cystogram by intravenous urography a much better outline of the bladder is obtained by introducing the dye directly into the bladder For such a picture 20 per cent Skiodan® or Urokon® is used These compounds are much less irritating than sodium iodide in case of extravasation Four ounces of the dye should be adequate It may be introduced into the bladder through a urethral catheter passed to the bladder or it may be forced with gentle pressure down the urethra into the bladder from a syringe held firmly against the urethral meatus If the patient can be moved x rays should be taken in the anteroposterior and lateral positions first with the bladder full and then in the anteroposterior position after the bladder has been emptied

Other methods of diagnosing a ruptured bladder are unsatisfactory By cystoscopy it is quite possible to overlook a defect in the mucosa which is hidden in one of the folds of the bladder wall An air cystogram may give a confusing picture when adjacent bowel is also filled with gas The old fashioned method of testing for perforation of the bladder by injecting a measured amount of fluid into the bladder and then

attempting to recover the same volume is unreliable

When searching for holes in the bladder the surgeon should keep in mind the possibility of associated injuries to adjacent viscera resulting in vesicovaginal or vesicorectal fistula. The former is characterized by the drainage of blood and urine

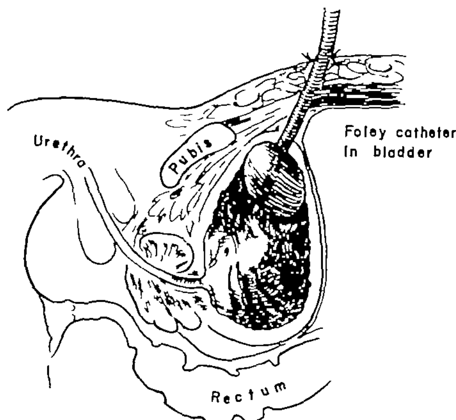


Fig 586 —Sketch emphasizing the position of a suprapubic tube in a cystotomy The tube should be brought out, not close to the pubis but well up toward the umbilicus, in order to facilitate subsequent closure of the sinus.

from the vagina. The latter should be suspected when air is passed with urine from the bladder

Treatment

Ordinarily a traumatic rupture of the bladder demands prompt surgical drainage and repair of the defect. There are to be sure rare exceptions as in the case of the patient seen recently at the Massachusetts General Hospital whose bladder was ruptured at the site of a cystotomy scar by a blow against the lower abdomen. In this instance a small amount of extravasated fluid was demonstrated in the extraperitoneal space Under conservative care with an indwelling urethral catheter and antibiotics the patient recovered But, as a rule undrained urine outside the urinary tract has a necrotizing effect which rapidly becomes serious unless recognized and released

In most cases of ruptured bladder with extraperitoneal extravasation of urine, the bladder is approached through a midline suprapubic incision and is opened through an incision in its dome It is explored for defects in the mucosa for foreign bodies for bladder tumors and for evidence of prostatic enlargement. From the outside of the bladder an attempt is made to close the traumatic rent in the wall by infolding the mucosa and muscularis using two layers

of chromic catgut sutures Even though there is no apparent evidence of intraperitoneal injury the surgeon should open the peritoneum if only to confirm his impression that there is no other lesion outside the bladder A very important part of the procedure is the placement of enough cigarette wicks to drain adequately all tissues permeated by extravasated urine

While it is possible to drain the bladder postoperatively with an indwelling urethral catheter alone a large tube for supplementary suprapubic drainage is desirable If the surgeon brings this suprapubic tube out at the upper end of the surgical abdominal wound well away from the pubic bone (Fig. 586) he will find that the subsequent sinus will close much more promptly than if the tube was placed at the lower end of the wound where attachment of the sinus tract to the pubic bone results in prolonged suprapubic drainage Ordinarily the suprapubic tube is removed in 4 days the urethral catheter is left in place until the suprapubic sinus has been dry for 6 days. The cigarette drains may be removed as soon as they have completed their job or as soon as drainage ceases which is about 6 or 7 days postoperatively

Intraperitoneal rupture of the bladder is managed in similar manner as follows

1 Exploration of the interior of the bladder and closure of the defect in its wall from without.

2. Exploration of the peritoneal cavity with aspiration of blood and urine and closure of the peritoneum from the outside with catgut sutures Drainage of the peritoneal cavity only if a localized collection of gross pus is found.

3 Drainage of the perivesical region with multiple cigarette wicks

4 Drainage of the bladder as in cases of extraperitoneal rupture

When the surgeon is confronted with a traumatic vesicorectal fistula he should perform a colostomy for the temporary diversion of feces This procedure along with a cystotomy to divert the urine may in itself effect a closure of the fistula.

Usually however it is preferable to repair the damage properly at the time of the initial exploratory laparotomy

URETHRA

Mechanism of Injury

In cases of severe fracture of the bony pelvis particularly in adult males where there is displacement of the pubic rami traumatic rupture of the membranous urethra should be expected This condition is much more common in adult males than in women and children In the region of the apex of the prostate the urethra is held rigidly as it pierces the layers of the triangular ligament For the most part the triangular ligament consists of strong fibrous bands which stretch tautly from the pubic arch back toward the ischiopubic rami With lateral compression of the bony pelvis the anteroposterior diameter is increased by anterior displacement of the pubic bones As the pubis moves forward it carries with it the triangular ligament and the enclosed urethra, tearing the membranous urethra from the prostatic urethra In the less severe fractures of the pelvis the urethra may be only partly transected Even without severe fractures of the pelvis the urethra may be badly lacerated or even transected by compression against the pubic bone in a straddle injury

Complete Transection of the Membranous Urethra

Signs —The common manifestations of complete rupture of the membranous urethra are

1 Suprapubic tenderness local muscle spasm and fullness in the lower abdomen associated with hemorrhage from vessels in the prevesical space and with extravasation of urine if there has been leakage of urine from the prostatic urethra proximal to the triangular ligament

2. Distended bladder secondary to patient s inability to void

3 Blood trickling from urethral meatus.

4 Fullness in perineum secondary to *periurethral hemorrhage*

5 Abnormal mobility of prostate by rectal examination resulting from absence of fixation of apex of gland to triangular ligament.

6 Palpation of urethral sound beneath rectal mucosa

7 Inability to catheterize urethra Even urethra gently with these instruments will do no harm If the examiner does succeed in getting into the bladder with his catheter under no circumstances should he remove the catheter He might not be so lucky the second time he tried

Figure 587 illustrates the location of extravasated urine and Figure 588 shows the rectal findings when the membranous urethra is transected

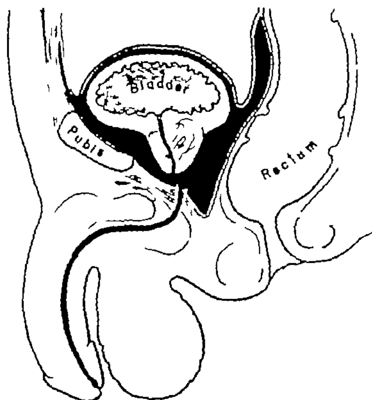


Fig 587 —Showing extent of extravasated urine (dark areas) in a case of complete transection of the urethra

though a soft rubber catheter can be inserted to the hilt and even though 2 or 3 ounces of thin bloody fluid can be obtained the catheter still may not be in the bladder it may have passed through the torn urethra into the prevesical space Difficulty in catheterizing a urethra may not necessarily be due to traumatic rupture it may be associated with an old stricture of the urethra or with a large prostate Before the examiner discontinues his efforts therefore he should try to get through to the bladder with a filiform and follower and with a soft catheter on a stylet. Probing the

Diagnosis —If the examiner is unable to pass a catheter to the bladder he should resort to a urethrogram (Fig 589) currently the most reliable diagnostic procedure A 1-ounce Asepto syringe with a urethral tip may be used to instill about 20 cc of a radiopaque dye through the meatus as far down the urethra as the tip will go. Rayopake® is used for this type of x ray examination X ray films are then made in the anteroposterior and if possible oblique views in order to reveal the extent of the spread of material into the prevesical space

TREATMENT —Once a diagnosis of complete rupture of the membranous urethra has been made the chief objective should be the reapproximation of the ends of the urethra with diversion of the urinary stream and drainage of extravasated fluid as soon as possible It is futile to attempt to suture the torn ends of the urethra through a perineal approach a good result

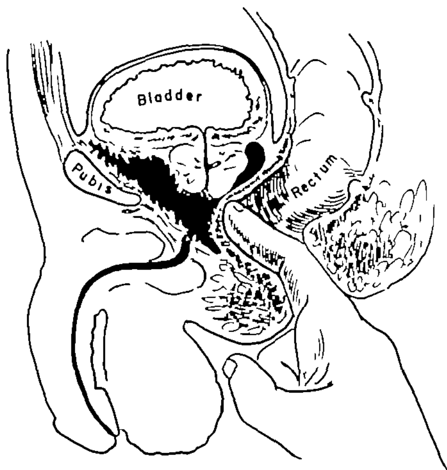


Fig 588 —Showing unusual mobility of the apex of the prostate in a patient with complete transection of the urethra.

cannot be expected in a field where tissues have been devitalized by trauma In fractures of the pelvis furthermore it is difficult to get the patient up into the necessary lithotomy position

Leadbetter has devised an ingenious arrangement to pull the apex of the prostate back into its original position and to hold it snugly against the membranous urethra by means of traction sutures placed on either side of the prostate and brought out through the perineum where they are tied over a piece of gauze

In the experience of the Massachusetts General Hospital satisfactory results have been obtained by pulling down the floor of the bladder by means of traction on a Foley catheter thereby approximating the edges of a transected membranous urethra sufficiently to enable them to heal with a minimum of scar tissue This of course involves a suprapubic approach through a cystotomy and the retrograde catheterization of the proximal portion of the urethra This is not an easy procedure because the prostate freed of its attachment at the triangular ligament tends to become acutely angulated up behind the symphysis pubis With the aid of a metallic sound in the prostatic urethra however the prostate can be returned to its normal position

Figure 590 shows how the ends of the severed urethra are brought into apposition by manipulation of the two segments with the Davis interlocking sounds Figure 591

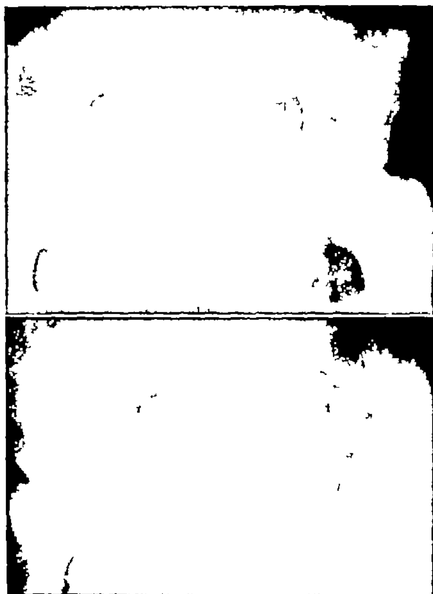


Fig 589 —Top anteroposterior view of pelvis of patient with traumatic rupture of the urethra The film, made following the urethral installation of 50 per cent Hypaque® shows extravasation of dye around the prostatic capsule and up both sides of the bladder Bottom oblique view showing extensive spread of dye up behind the bladder

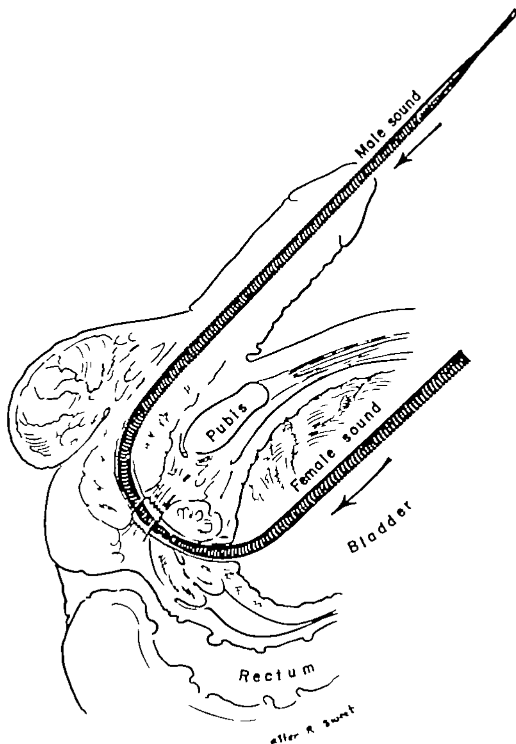


Fig 590 —Illustrating how the opening of the distal portion of a completely severed urethra is brought into approximation with the proximal opening of the urethra by means of two inter locking sounds—a male sound introduced through the urethra, and a female sound passed from above downward through the bladder and prostatic urethra The female sound is used to facilitate approximation of the ends of the sounds as the male sound is passed through the site of the rupture and up into the bladder (After Davis G G)

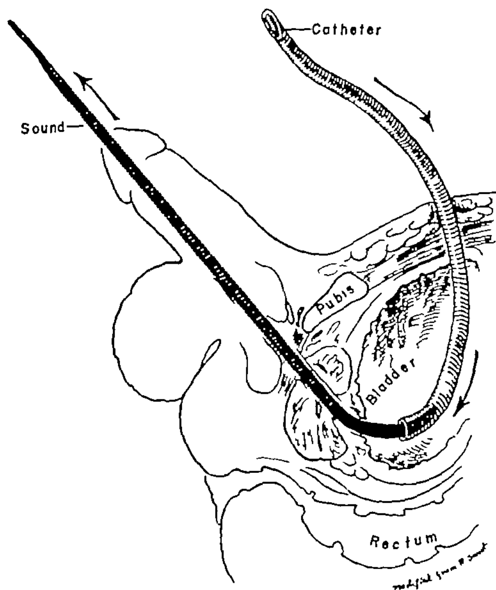


Fig 591 —Illustrating how a soft rubber catheter is attached to the end of the male sound and then drawn down through the bladder prostatic urethra through the site of the rupture and out to the urethral meatus as a leader for the insertion of the Foley catheter (After Davis, G G)

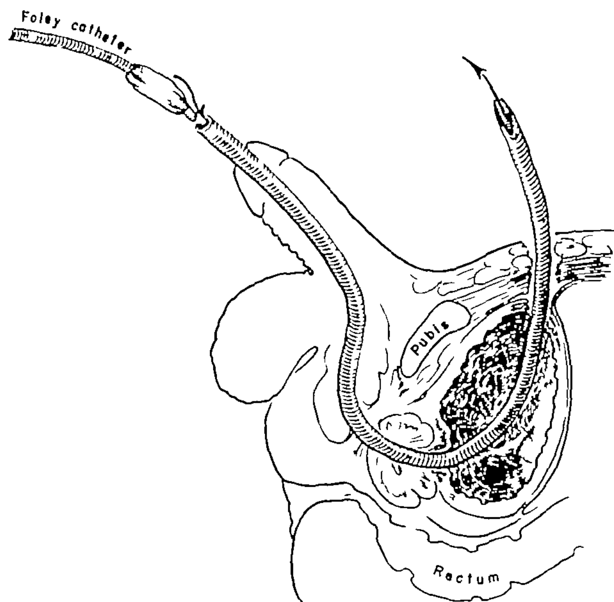


Fig. 592.—Demonstrating how a Foley catheter is attached to the distal end of a plain catheter and then drawn through the ruptured urethra into the bladder for consant drainage

indicates the method of pulling a soft rubber catheter through the realigned urethra Figure 592 illustrates how the Foley catheter is led back through the urethra into the bladder and Figure 593 demonstrates the Foley catheter in position ready for traction with a Boston anchor or with attachment to the thigh through elastic bands catheter is released at the end of 72 hours. The suprapubic tube may be removed on the seventh day and the urethral catheter on the fourteenth day after the initial procedure

When the patient is in a desperate condition, the surgeon may not be justified in spending the time necessary to approxi-

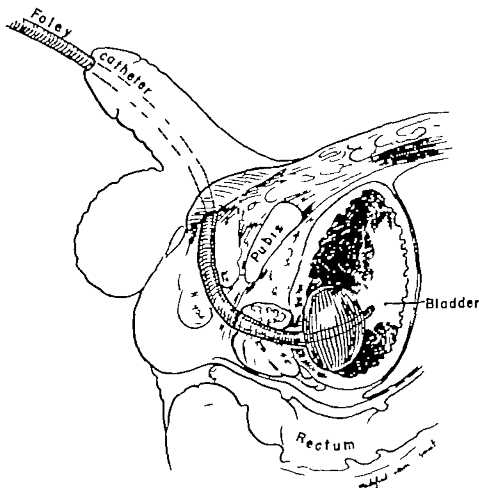


Fig 593 —A Foley catheter in place for constant drainage and for gentle downward traction on the bladder floor in order to hold the ends of the ruptured urethra in approximation.

mate the ends of a severed urethra. In that case the surgeon should limit his efforts to a simple cystotomy Just as soon as the patient can stand more surgery however efforts to re-establish the continuity of the urethra should be made If possible this ought to be done within 1 week. Otherwise the proximal end of the urethra may be pulled under the bladder or up behind the pubic bone by scar tissue producing a very

To divert the urine temporarily the bladder is closed around a No 30 F mushroom catheter care being taken to bring out the catheter well away from the pubic bone. Cigarette wicks should be used generously to drain the retropubic space A perineal incision may be necessary to drain blood and urine localized around the urethra.

Postoperatively traction on the Foley

difficult problem for the urologist who is asked later to connect the bladder with the distal urethra

Incomplete Rupture of the Membranous Urethra

Signs —To a certain extent the early signs of a partial transection of the mem branous urethra are similar to those of a complete rupture They are

1 Severe pain and localized swelling in the pubic area.

2. Blood trickling from the urethral meatus.

3 Marked dysuria if the patient is able to void at all

4 Swelling and ecchymosis of the per ineum and scrotum if there has been ex travasation of urine and bleeding distal to the triangular ligament.

Diagnosis —In the case of incomplete rupture however there is no abnormal mobility of the prostate and with good for tune a catheter may be passed to the blad der *If the patient is able to void for the* three-glass test of urine this is of great diagnostic help In this test the patient is directed to pass portions of his urine into three successive glasses If the first speci men is bloody and the specimen is clear an injury to the lower urinary tract is con sidered to be a certainty When blood is found in a single voided specimen the source of the blood—whether from the kid ney the bladder or the urethra—is not certain If at least partial continuity of the urethra is preserved a urethrogram show ing some of the dye outside the urethra and some dye passing into the bladder will confirm the clinical diagnosis

Treatment.—In cases of incomplete rupture of the urethra excellent results may be obtained simply by passing a No 18 Foley catheter with a 5 cc balloon down the urethra into the bladder for a 2 week period of constant drainage Evidence of extensive extravasation of blood and urine in the perirenal area merits local incisions for drainage in the area involved.

Rupture of the Distal Urethra

Where the portion of the urethra distal to the membranous segment is transected or even shortened by the loss of a segment of whole urethra the diagnosis should be obvious from physical examination and the passage of a catheter These situations lend themselves well to primary closure of the defect from below and temporary di version of the urine through a perineal urethrostomy

Catheter Drainage

Meticulous attention to details will en able a surgeon to avoid many of the un desirable complications of catheter drain age Although a large urethral catheter may at times be necessary to drain blood clots from a bladder ordinarily a No 18 or better still a No 16 Foley catheter is adequate A relatively small catheter facili tates the drainage of urethral secretions around the catheter while a large catheter encourages the development of urethritis and of subsequent urethral stricture by in terference with free drainage between the catheter and urethral mucosa Strictly ster ile tubing and sterile stoppered drainage bottles should be used with the catheter Previous studies by Buddington and Graves have shown that infection may travel in a retrograde fashion from a dirty drainage bottle up into the bladder At no time should the drainage tube be disconnected and the open end of the catheter allowed to rest on the contaminated bedding The catheter should be wrapped in a sterile piece of gauze if it must be disconnected To avoid the need of disconnecting the drainage system for the purpose of irrigat ing the bladder the use of a closed irrigat ing system as described by Nathaniel Al cock is recommended

For an irrigating solution sterile water may be used or sterile normal saline solu tion If the lumen of an indwelling ure-thral catheter tends to become obstructed quickly with calcareous deposits precipi

tated from an alkaline urine Suby s Solution G may be used as an irrigant The formula of Solution G Concentrate is as follows

Citric acid	5 155.552 Gm.
Magnesium oxide	614 4 Gm
Sodium hydroxide	555.2 Gm.
Distilled water added to make—	20,000 cc.

For irrigations this is diluted 1 7 with sterile water Solution G has a pH of 4 0 yet it is relatively nonirritating to the bladder mucosa It will readily dissolve the calcium phosphate deposit on a catheter

COMPLICATIONS

Although postoperative complications sometimes imply a lack of surgical skill or a failure to observe minute details of an operation they also occur because of circumstances beyond the control of the surgeon Their proper management is facilitated by an understanding of their etiology The following are some of the complications that may arise

PERSISTENT SUPRAPUBIC SINUS FOLLOWING A CYSTOTOMY —After the removal of a suprapubic tube a cystotomy opening in the suprapubic area should close solidly within a week. Persistent drainage of urine from the wound may be associated with the following etiological factors

a) Fibrous attachment of the suprapubic sinus tract to the pubic bone which interferes with retraction of the scar

b) Presence of a foreign body within the bladder

c) Stricture of the urethra.

d) Obstruction at bladder neck by an enlarged prostate

e) Unsuspected malignancy of the bladder

f) Osteomyelitis of the pubic bone resulting from inadequate drainage of the prevesical space

g) Severe wound sepsis.

h) Lowered vitality of tissue in an elderly individual whose diet has been inadequate

Rarely is it necessary to excise a persistent suprapubic sinus correction of the causative factor will result in a spontaneous closure.

INFECTION OF THE HIP JOINT —This very unfortunate situation rarely occurs in adults It is usually seen in children with very severe pelvic fractures in whom extensive extravasation of blood and urine *has been drained inadequately or even* overlooked entirely

INCONTINENCE OF URINE.—Incontinence of urine is almost never seen in adults because the internal and external sphincters are well removed from the site of trauma Occasionally incontinence is found in children after they have been discharged from the hospital. In the experience of the Massachusetts General Hospital incontinence is of a functional nature unhappy children resort to this maneuver as a subtle plea for the loving care which they received in the hospital, which frequently they miss at home

STRICTURE OF THE URETHRA —This inevitably follows the spontaneous union of a torn urethra Neglected the stricture may be the source of permanent trouble. Treated properly its management is easy To prevent permanent strictures in cases of complete rupture of the urethra the urethral dilations should be started before the fibrous tissue has closed down the urethra to a tiny opening Two weeks after the urethral catheter has been removed metal sounds Nos 18 through 26 F should be passed Thereafter the interval between dilations is lengthened by adding 1 month to the previous interval until a 6-month period is reached Then the urethra may be dilated every 6 months for 2 years By that time the scar will be pretty well softened and the patient should be able to get along comfortably without further dilations

IMPOTENCE.—The incidence of impaired ability to enjoy sexual relations after severe fractures of the bony pelvis is fairly common The etiological relationship between this type of trauma and impotence is rendered difficult by the complicated physiology of the act of copulation. The fibrous changes which may result from the accumulation of blood urine and infection around the prostate certainly could

be expected to impair a man s former sexual capacity yet equal impairment might occur on a purely functional basis in a man worried perhaps by financial problems or by the fear that sexual activity may activate a smouldering backache The differential diagnosis between functional and organic impotence is furthermore extremely difficult to establish Even if it does seem that the injury is responsible for the condition of impotence treatment is unsatisfactory There are no practicable surgical procedures to overcome this misfortune Psychotherapy by an understanding wife is more likely to salvage a part of the patient s former virility than is the administration of male hormones In fact the use of androgens is contraindicated because of their tendency to produce excessive congestion of the prostate and sometimes hemorrhage or obstructive symptoms.

PERSISTENT PYURIA —When a patient s urethral catheter is removed the pus cells in his urine should clear up within 2 or 3 weeks under proper therapy If the infection in the urinary tract does not subside promptly the physician should not continue indefinitely the administration of antibacterial agents Instead he should consider the common causes of persistent infection of this type These are

a) Foreign body—for example a spicule of bone a tumor or a stone in the kidney bladder or urethra

b) Stasis of urine as in pre-existing hydronephrotic kidney or in a bladder which does not empty completely

c) Chronic prostatitis especially when accompanied by presence of prostatic calculi.

d) Presence of a particularly resistant organism.

e) Diabetes or tuberculosis

The following routine is suggested for such cases of persistent pyuria

a) The simple two-glass test in which the patient voids first into one glass and then into a second If both specimens are purulent the infection probably involves the upper and lower urinary tract if only the first specimen contains pus cells the infection most likely involves only the prostate and urethra.

b) Culture of the urine with sensitivity tests to indicate which drug is effective

c) Intravenous pyelogram to eliminate unsuspected pathology in the upper urinary tract

d) Cystoscopy

Once the possibility of concomitant factors is excluded it should be possible to clear up the infection without too much difficulty

CAUSES OF DEATH —Even with the availability of antibiotics and modern surgical technique the mortality among patients with urinary complications in fractures of the pelvis is still high Pulmonary emboli continue to claim a few patients Others die on the third or fourth day without apparent cause The latter may be the victims of multiple fat emboli, which some authorities claim are common in this type of injury If routine autopsies were done on all patients who die of complications due to pelvic injuries probably it would be learned that many patients succumb to undrained sepsis or to inadequate treatment of shock. Prophylactically therefore the need for stringent measures to combat shock and the importance of minimal manipulation of fractured segments of the pelvis should be emphasized It should be borne in mind furthermore that in case of doubt concerning the possibility of a ruptured viscus or an accumulation of pus more is gained from surgical exploration than from watchful waiting

In the management of urological complications of the genitourinary tract the importance of the following procedures should be emphasized

1 Retrograde pyelogram to diagnose a ruptured kidney

2 Postoperative intravenous pyelogram in all cases of renal or ureteral surgery

3 Cystogram to reveal a ruptured bladder

4 Prompt drainage of extravasated blood and urine around a ruptured kidney bladder or urethra

5 Early approximation of the ends of a ruptured urethra

6 Postoperative urethral dilations in cases of urethral repair

7 Adequate urological study in those cases in which pyuria does not subside promptly

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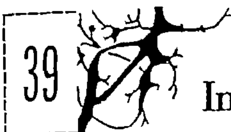
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Injuries of Peripheral Nerves

VARIOUS DEGREES OF injury to the peripheral nerves follow different types of trauma to the extremities * The nerve injuries most commonly seen in civilian practice are caused by direct severance of the nerve by a sharp object severe contusion over a bony prominence which often accompanies dislocation of the shoulder and fractures in the region of the elbow or head of the fibula prolonged compression when the arm of a stuporous or anesthetized individual is compressed against the chest or a solid object overprolonged application of a tourniquet and traction from dislocation of the knee or violent displacement of the shoulder girdle In battle casualties the nerve may be directly severed by a projectile or injured by the blast wave as a high velocity bullet passes through the neighboring soft parts or shatters a bone In order to explain the ensuing neurological disturbances it is necessary to consider the anatomical structure of nerve and its pathological reaction to injury

ANATOMICAL STRUCTURE

The spinal nerves arise from the cord at each segment of the neuraxis as a posterior (sensory) and anterior (motor) root These roots join together in the intervertebral foramen and form a single nerve this is covered by a fibrous tissue sheath the epineurium which is in continuity with the dura mater Within this sheath the nerve is divided by fibrous connective tissue septa into bundles of fibers or funiculi each of which has a fibrous tissue covering known as the perineurium Each funiculus in turn contains numerous nerve fibers A nerve fiber consists of a central axon surrounded by myelin, a complex substance containing proteins and lipids which forms a sheath of variable thickness around each axon Surrounding the myelin sheath is the neurilemma or sheath of Schwann and this in turn is surrounded by a thin layer of fibrous connective tissue the endoneurium which is the inward extension of the perineurium The myelin sheath is interrupted periodically by con

*The manuscript for this chapter was written prior to the publication of the Veterans Administration medical monograph entitled *Peripheral Nerve Regeneration* edited by Dr Barnes Woodhall and Dr Gilbert W Beebe. Therefore it has not been possible to refer to this very worth-while contribution, which gives detailed statistics of 3,656 injuries to peripheral nerves incurred by 2,714 veterans of World War II and which contains a wealth of information on all factors that play a role in nerve regeneration after neurolysis and nerve suture.

strictions the nodes of Ranvier The larger more heavily myelinated fibers which conduct with the greatest velocity transmit skeletal motor impulses or tactile and postural sensation The smaller lightly myelinated and unmyelinated fibers carry impulses to the blood vessels sweat glands and arrectores pilorum muscles in addition to the greater portion of the impulses transmitting pain the rate of conduction in these is slow It is of interest that the larger fibers are most vulnerable to injury by compression and the smaller to interruption by local anesthetic solutions

Each large peripheral nerve is made up of a number of fascicles or funiculi After each branch enters a nerve its fibers as Sunderland and Ray have found ascend for a short distance within a single funiculus But at a higher level in the nerve the funiculus loses its identity because its fibers intermingle with those of other funiculi. In the course of nerve regeneration after division and suture it is manifestly impossible to secure anything like nearly perfect regeneration Not only is it impossible for individual sensory motor or autonomic fibers to find their original distal Schwann tubes but even the gross funicular pattern can never be accurately reapposed



Fig 594 —Top distal end of severed nerve (*at right*) entering neuroma The nerve is cut longitudinally in the course of its fascicles Inset magnified view of severed fascicles Regenerating and branching axons are shown as they enter and ramify in end-bulb scar (Stained with Bielschowsky silver stain.)

DEGENERATION AFTER NERVE INJURY

When a nerve is severed the capacity of its distal decentralized fibers to conduct is lost in about 19 hours Microscopic evidence of degeneration occurs more slowly with disintegration of the central fiber and fragmentation of the myelin, which disappear within 3 weeks. This is the histological process of wallerian degeneration which is accompanied by electrical changes in nerve and muscle known as the "reaction of degeneration" (R.D) From then on only the fibrous septa and the Schwann sheaths are left These structures are important in regeneration since

they remain intact to receive downgrowing axons over a period of many months *

When a nerve trunk is cut across an end-bulb *neuroma* gradually forms at the central end (Fig 594) This consists of axon tips which split and increase in num ber as they grow out of the ends of the Schwann tubes Not finding any distal tubules to enter they curl up on themselves to form a bulbous tip composed of nerve elements and fibrous tissue A small end bulb (*glioma*) develops at the distal stump (Fig. 595) it is composed of the glial elements of the Schwann sheaths which are also enmeshed in scar tissue When only the side of a nerve is injured the emerging axons form a *lateral neuroma* In addition various degrees of endoneurial fibrosis may lead to fusiform *neuromas in-continuity* when a nerve trunk has been contused or stretched without rupture of its epineu rium.

When a nerve is injured temporary changes take place as far back as the nerve cells in the anterior horn and posterior root ganglion, where there is swelling and chromatolysis A certain number of these cells perish As a result there is a brief latent period (10 days) before the axons again begin to grow Whenever a proliferating axon tip succeeds in entering a distal empty Schwann sheath it grows at the rate of 3 mm a day† down the empty tu bule Whether it eventually functions or not depends on its reaching an appropriate sensory motor or sympathetic end-organ When this final stage is reached myelin is gradually redeposited around the sensory and motor fibers

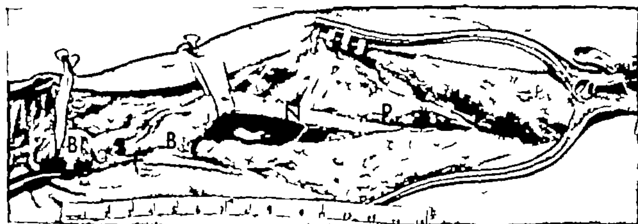


Fig 595 —Gunshot wound of median nerve in midforearm. Surgical exposure several months after injury shows wide retraction of end bulbs (B) with intervening scar (S) The prox imal neuroma lies to right, with the nerve (N) above emerging from under the superficial head of the pronator teres muscle (P)

TYPES OF NERVE INJURY

Seddon has divided nerve injuries into three categories neurapraxia, axonotme sis and neurotmesis

Neurapraxia —In neurapraxia there is concussion with brief physiological loss of function and return to normal conduction within a period ranging from minutes to a few weeks There is no axonal degenera tion

Axonotmesis —This is also an injury in continuity but with more severe contusion and wallerian degeneration of the axons

* It has been shown that in the course of time the Schwann sheaths gradually contract, with the opportunity for regeneration beginning to decrease after 6–9 months In addition, the striated muscle cells atrophy and become replaced by scar tissue after several years so that effective recovery of function ultimately becomes impossible.

† Growth of the advancing axon tip is faster near the spinal cord and becomes distinctly slower in the periphery according to Sunderland. Allow ing for the period of delay for axon proliferation to start and bridge the gap after a nerve suture then to grow down a considerable length of nerve an inch a month is a fair allowance for over-all rate of regeneration

within their Schwann sheaths. Since the latter remain intact regeneration will ultimately be complete or nearly so

Neurotmesis —In neurotmesis there is complete severance of a nerve trunk or some of its funiculi.

Sunderland has proposed a more complete classification which takes into account both the pathological process and the clinical outcome. It contains five degrees of injury

First Degree —Concussion or compression of fibers is present without degeneration. Recovery may begin in a period of minutes and is always complete within a month, since few if any fibers degenerate

Second Degree —The axons are destroyed but their Schwann sheaths remain intact Therefore wallerian degeneration follows but each axon regenerates within its endoneurial tubule and eventually reaches its original end-organ.

Third Degree —Here there is a more serious injury in continuity with the epineurium preserved but with disorganization of many of the funiculi and endoneurial tubules There is usually some intrafunicular hemorrhage and resultant fibrosis.

Fourth Degree —With more serious injury in continuity there is disruption of all the funiculi and individual nerve fibers This results in severe endoneurial scarring and a dense neuroma in-continuity No useful regeneration can bridge the barrier of scar tissue and so the scar tissue must be excised and the healthy ends of the nerves sutured

Fifth Degree —The nerve trunk is severed with retraction of its ends and the formation of a proximal neuroma and distal glioma (Fig 595)

After complete severance or intraneuronal destruction there is immediate and total paralysis of all forms of sensation muscular movement and vasomotor and sudomotor activity The ability of the distal segment to conduct an electrical stimulus *is lost within a few hours Chronaxy rises* and the paralyzed muscle fibers begin to fibrillate By the end of 2–3 weeks the electrical reaction of degeneration is complete with well advanced fragmentation of the axons and disintegration of their surrounding myelin Muscular atrophy becomes noticeable within a month

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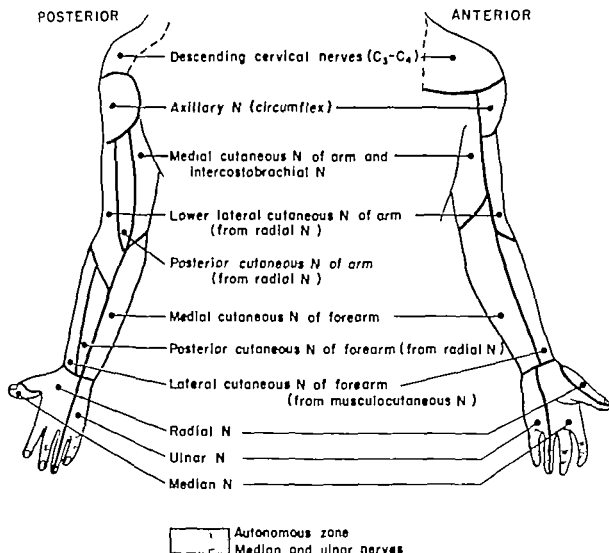


Fig 596 —Cutaneous sensory nerves to upper extremity (Modified from Haymaker W and Woodhall, B *Peripheral Nerve Injuries Principles of Diagnosis* [2d ed Philadelphia: W B Saunders Company 1953])

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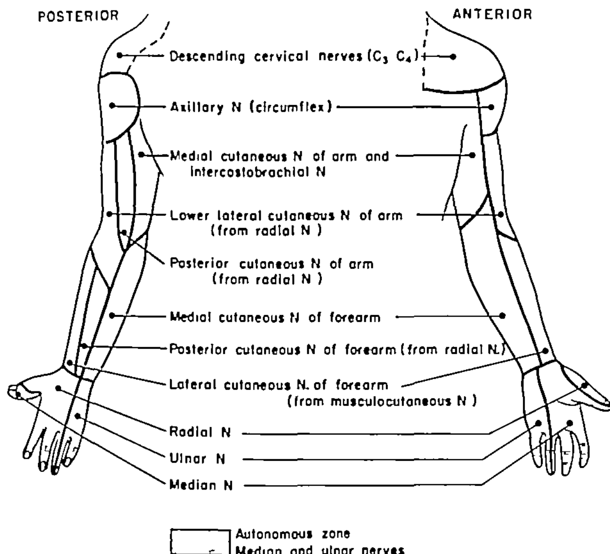


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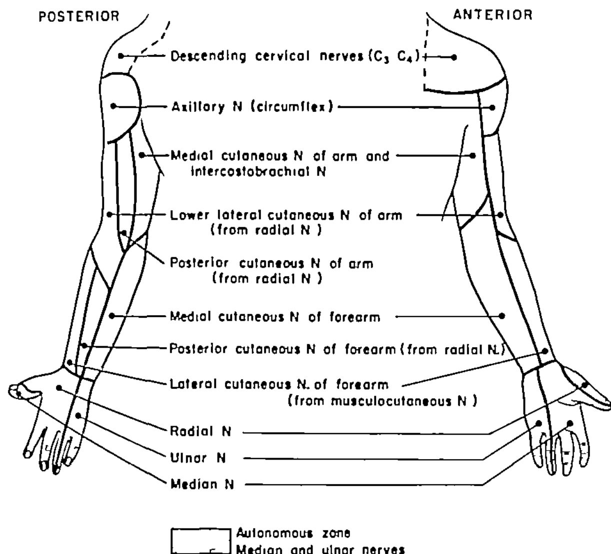


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musculocutaneous nerve has been injured and the biceps paralyzed When dealing with an unco-operative individual or with a case of suspected hysterical paralysis in fallible evidence can always be obtained

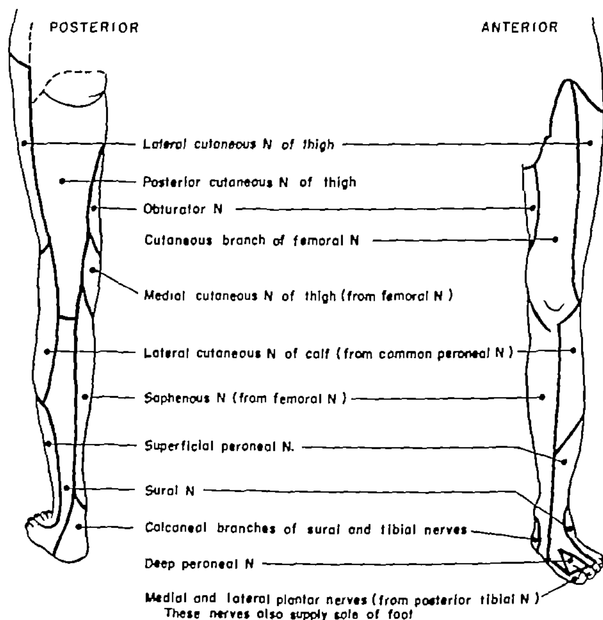


Fig 597 —Cutaneous sensory nerves to lower extremity (Modified from Haymaker W., and Woodhall B *Peripheral Nerve Injuries Principles of Diagnosis* [2d ed Philadelphia: W B Saunders Company 1953])

by intraneuronal stimulation of the nerve or by electromyographic testing of the mus cles (Haymaker and Woodhall and Mari nacci) or by the absence of sweating and elevated skin resistance (Richter and Katz) The latter follow the pattern of the cutaneous sensory supply

A more difficult matter to diagnose is the pathological extent of nerve injury First second and third-degree injuries (neurapraxia axonotmesis and even a partial intraneuronal disruption) will make a worth while or even a perfect recovery if left alone or they can be treated best by a delayed neurolysis at a subse

quent date If there is an open wound that requires closure the state of the underlying nerves can usually be observed at the time of debridement of the wound When there has been a closed fracture dislocation of a joint or compression of the extremity the surgeon must wait and observe the course of events It is always safe to wait for a number of months since the chances of recovery after a delayed repair are not appreciably lessened by waiting up to 6 or even 9 months With the knowledge that there is a latent period of about 10 days before axonal growth starts and then an advance of 2–3 mm a day lack of progress or the reverse can easily be observed Tinel s sign is not always reliable evidence of worth while regeneration but the physician can observe the progressive innervation of muscles charted in Tables 37 and 38 and obtain electrical evidence of their reinnervation by the reduction in chronaxy

TABLE 37 —SPINAL AND PERIPHERAL INNERVATION OF MAJOR MUSCLES OF ARM AND HAND

	Upper Arm		Forearm		Hand	
Musculocutaneous C5–7	Coracobrachialis	C6 7				
	Biceps	C5 6				
	Brachialis	C5 6				
Axillary C5–6	Deltoid	C5 6				
Radial, C5–8	Triceps	C7 8	Extensor carpi radialis	C6 7 8		
	Brachioradialis	C5 6	Supinator	C5 6		
			Extensor digitorum	C7 8		
			Extensor digiti minimi	C7 8		
			Extensor carpi ulnaris	C7 8		
			Abductor pollicis longus	C7 8		
			Extensor pollicis longus and brevis	C7 8		
			Extensor indicis	C7 8		
Median,			Pronator teres	C6 7	Abductor pollicis brevis	C8 T1
C6–7 Lateral head mainly to forearm muscles			Flexor carpi radialis	C6 7 8	Opponens pollicis	C8 T1
			Palmaris longus	C7 8 T1	Flexor pollicis brevis	C8 T1
C8 T1 Medial head mainly to intrinsic muscles of hand			Flexor digitorum sublimis	C7 8 T1	First and second lumbricals	C7 8
			Flexor digitorum profundus (F2, 3)	C7 8 T1		
			Flexor pollicis longus	C8 T1		
			Pronator quadratus	C7 8 T1		
Ulnar, C8 T1			Flexor carpi ulnaris	C8 T1	Abductor digiti minimi	C8 T1
			Flexor digitorum profundus (F4 5)	C8 T1	Opponens digiti minimi	C8 T1
					Third and fourth lumbricals	C8 T1
					Interossei	C8 T1
					Adductor pollicis	C8 T1
					Flexor pollicis brevis	C8 T1

*The muscles are listed in the order of origin of their motor branches from the main nerve trunks, from above downward. With this knowledge it is possible to figure the level at which any major nerve is transected, and likewise to follow the rate of motor reinnervation after repair or spontaneous regeneration

and the cessation of fibrillation, together with the appearance of voluntary contraction potentials in the electromyogram

BEST TIME TO EXPLORE AN INJURED NERVE

The British (Seddon) advocate a month s delay in the suture of a severed nerve In the case of a gunshot wound all American neurosurgeons agree that this delay is advisable The blast injury of a high velocity projectile produces so much edema, so many minute hemorrhages and so much necrosis that it is impossible to tell how much of the swollen stumps of the nerve will remain viable Furthermore the epineurium is so soft that it will not hold sutures This reaction subsides within a month at which time the scarred end bulbs can be cut back to healthy nerve tissue ideal for proper approximation and suture At the preliminary debridement of a gunshot wound the surgeon should do no more than examine the condition of the nerve noting whether it is severed or merely contused stop bleeding and trim away necrotic avascular tissue. Under these conditions it is only permissible to approximate or tack down the severed ends of a nerve with a single stitch to prevent their further separation. Definitive repair of the nerve is best carried out at a secondary operation 3–4 weeks later

In the case of a relatively clean laceration with a knife or other sharp object, immediate repair is advocated by the surgeons at the Massachusetts General Hospital. In such a wound there will be no serious damage to the nerve above or below its point of transection the epineurium is not softened and there seems to be no

TABLE 38 —SPINAL AND PERIPHERAL INNERVATION OF MAJOR MUSCLES OF LEG AND FOOT*

	THIGH			
Femoral: L2–4	*Rectus femoris*	L2–4		
	Vastus lateralis	L2–4		
	Sartorius	L2–4		
	Vastus intermedius and medialis	L2–4		
Obturator: L2–4	Adductor magnus	L2–4		
	Adductor longus and brevis	L2–4		
	Gracilis	L2–4		
Sciatic: L4–S3	Adductor magnus	L5–S1		
	Semimembranosus and semitendinosus	L4–S2		
	Biceps femoris	L5–S2		
	POSTERIOR CALF		**FOOT**	
Tibial: L4–S3	Gastrocnemius	S1 2	Intrinsic plantar muscles which are difficult to test	L5–S3
	Soleus	L5–S2		
	Tibialis	L5–S2		
	Flexor digitorum longus	L5–S2		
	Flexor hallucis longus	L5–S2		
Peroneal: L4–S2	Superior branch:		Extensor digitorum brevis	S1 2
	Peroneus longus and brevis	L5–S2		
	Deep branch:			
	Tibialis anterior	L4 5		
	Extensor digitorum longus	L4–S2		
	Extensor hallucis longus	L5–S2		

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reason for delay Results after early repair of severed nerves and neighboring structures under these conditions have been all that can be expected

TECHNIQUE OF NERVE SUTURE

The following principles are important for the effective suture of a nerve They will be listed first and then discussed in more detail below

1 Suture must be performed at a level of healthy epineurium with preservation of the nerve funiculi and relative freedom from scar

2. The suture should be made with very fine nonabsorbable stitches and accurate apposition of the epineurium

3 There should be as little rotation of the nerve ends as possible

4 The completed suture must not be under tension

5 The sutured nerve should be placed in as healthy a bed of tissue as circumstances permit.

6 The suture must be protected from disruption by immobilizing the contiguous joints

Except in the case of a fresh laceration exploration of an injured nerve should be carried out under local anesthesia. This is best done by infiltrating the tissues in the line of incision with procaine or longer lasting Xylocaine® with added Adrenalin® Care should be taken not to infiltrate the nerve itself because its function must be tested electrically in case a neuroma in-continuity is found (A tourniquet cannot be used if local anesthesia is employed) Long incisions should be planned with care to permit satisfactory exposure and to avoid linear contracting scars across the joints When the position of the retracted end-bulbs is uncertain these can be located most easily by exposing the nerve above and below in healthy tissue It is always advisable to free up a considerable length in order to gain slack. This is quite harmless provided that care is taken not to injure any important branches Fortunately nerves have an extensive longitudinal blood supply so that their lateral vascular supply can be sacrificed over many inches without risk of ischemic necrosis

Methods

With the point of injury clearly exposed the course to follow will be governed by the type of wound When there is a neuroma in-continuity it is important to decide whether an adequate number of fibers can grow down through the zone of endoneurial scarring This cannot be detected directly after injury but after several weeks have elapsed a fairly accurate assessment can be made by one of the following methods

METHOD 1 —Electrical stimulation by means of an alternating-current transformer producing 60-cycle sine waves or a condenser discharge giving square-topped waves of 1 millisecond duration at a frequency of 60 cycles If one of these stimulators is not available a faradic current of the type supplied by the Harvard inductorium will do

Sensory —Can the patient feel a stimulus applied to the distal end of the neuroma?

Motor —Does a stimulus of 10–15 volts above the neuroma produce any contraction of the muscles below? This test will be painful unless the nerve is blocked by injecting local anesthetic solution into its trunk a few centimeters above

METHOD 2 —Palpation of the segment of nerve injured in order to detect the presence of a constrictive scar

METHOD 3 —Infiltration of sterile saline solution checking to see if the solution passes areas of suspected fibrosis

An evaluation of the end results of surgery in large numbers of nerve injuries in veterans of World War II (recently completed for the National Research Council and Veterans Administration) has shown that neurolysis carried out in cases tested by these methods was generally superior to resection of the neuroma and suture

When there is no chance of effective regeneration through a neuroma in-continuity or when there has been separation of the nerve ends (Fig 595) it is necessary to resect the scarred portion back to healthy tissue This is best done by making serial of healthy nerve in which the individual fascicles stand out as multiple small projections Before resecting any neuroma in-continuity a marker suture should be placed at corresponding points in the epineurium above and below the area to be

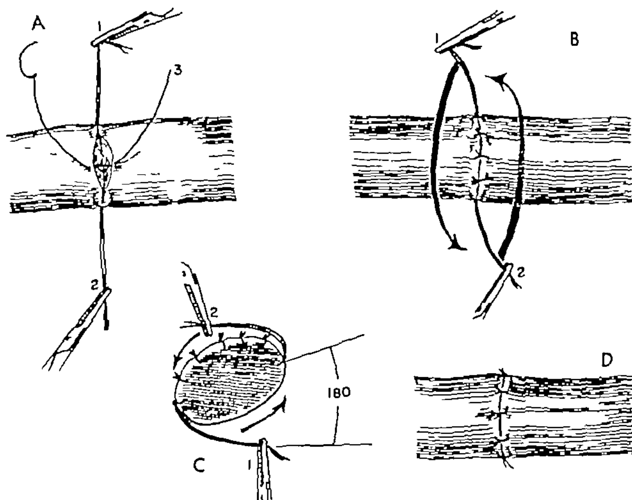


Fig 598 —Technique of neurorrhaphy Prior to suture the end-bulbs were cut back to healthy nerve structure free from scar (Procedures described in the text have also been utilized to permit approximation and suture free from tension and with minimal rotation.) A, stay sutures (*1* and *2*) placed on opposite sides to approximate severed ends of nerve with minimal rotation. Epineurial suture (*3*) is started B epineurial suture on anterior surface completed. The long end of stay suture *2* is passed beneath the nerve while suture *1* is drawn across its surface in the opposite direction C method of rotating nerve Traction on stay sutures will now present its posterior aspect. D epineurial suture completed

sections with a safety razor blade held in a hemostat until the separate fascicles can be seen clearly by the naked eye or better still with the aid of a magnifying glass or spectacles. The zone of scar tissue in a neuroma has the pale uniform texture of "fish flesh" in striking contrast to the characteristic appearance of the cross-section resected, so that the free ends can be sutured afterward with a minimum of rotation

For suturing, it is best to use either very fine (6-0) black silk or 3-mil tantalum wire (This is available swedged onto curved needles) The metallic stitches are preferred because they can be seen in x ray

films and any subsequent separation of the suture line can thus be detected

When the two ends of healthy nerve are ready for approximation stay sutures should be placed in the epineurium 180 degrees apart tied and held taut at either side by fine hemostats Individual stitches are then placed and tied 1 or 2 mm apart on the anterior exposed half of the circumferences taking care to include only the firm thick epineurial sheath and to tie each suture snugly (Fig 598) When this row has been completed there should be an accurate approximation of the outer sheath of the nerve with no protrusion of its contents One of the original stay sutures is then passed beneath and the nerve trunk rotated 180 degrees to expose its posterior wall for suture After this has been completed all the way around the repaired nerve is dropped back into a bed of healthy muscle or adipose tissue

In addition to accurate approximation it is of vital importance that the suture be free from any tension Sometimes it is necessary to compromise by not carrying the resection all the way back to entirely normal tissue Generally however and particularly in civilian type injuries adequate slack can be gained by one of the following methods

Adequate Extent of Neurolysis — This may include if necessary the entire length of the forearm upper arm thigh or lower leg. The extent of neurolysis however should not be carried any farther than necessary In wartime experience sciatic and tibial sutures seemed to do poorly when the nerve was freed up over the greater part of the leg

Proper Positioning of Neighboring Joints So That the Course of the Nerve Is Shortened —In case of injuries to the brachial nerves the elbow and wrist are flexed the hip is extended, and the knee flexed after a sciatic suture

Transposition or Rerouting of the Nerve.—A standard procedure in ulnar nerve sutures is to shift the nerve from its epicondylar groove to a position in front of the elbow As Learmonth first recommended it is advisable to cut the flexor muscles a few millimeters from their insertion in the medial condyle to lay the ulnar nerve alongside the median and then to resuture the muscular attachments This procedure is illustrated in Figure 599 When in addition the elbow and wrist are flexed it is possible to close defects up to nearly 10 cm in length In treating old fractures of the internal condyle with injury to the nerve in the epicondylar groove the orthopaedic surgeons at the Massachusetts General Hospital often resect a portion of the condyle in addition to transposing the ulnar nerve

Other maneuvers of similar type are (*a*) transposing the median nerve into a more superficial position by cutting the superficial head of pronator radii teres muscle and resuturing it behind the nerve (*b*) passing the radial nerve in front of the humerus so that after suture it passes in a straighter course through a tunnel beneath the biceps muscle (this step gains only 3–4 cm in length) (c) resection of the parotid gland in difficult sutures of the facial nerve as recommended by White The latter procedure gains 1 or 2 cm. of added slack and permits a far better exposure for deep sutures between the ramus of the mandible and the stylomastoid foramen

Shortening the Humerus or Femur as Proposed by Dandy —This is a logical step in cases of ununited fractures Also the clavicle can be shortened or excised and the shoulder moved inward in difficult repairs of plexus injuries

For overcoming extensive defects when none of the foregoing procedures has yielded sufficient slack for a satisfactory suture final recourse may be had to the following procedures

End-Bulb Suture —After the nerve has been freed over a maximal extent and rerouted into its shortest course full advantage has been taken of joint positioning and it is just possible to approximate the widely separated end bulbs these may be sutured. The elbow or knee is then gradually straightened a few degrees a day by

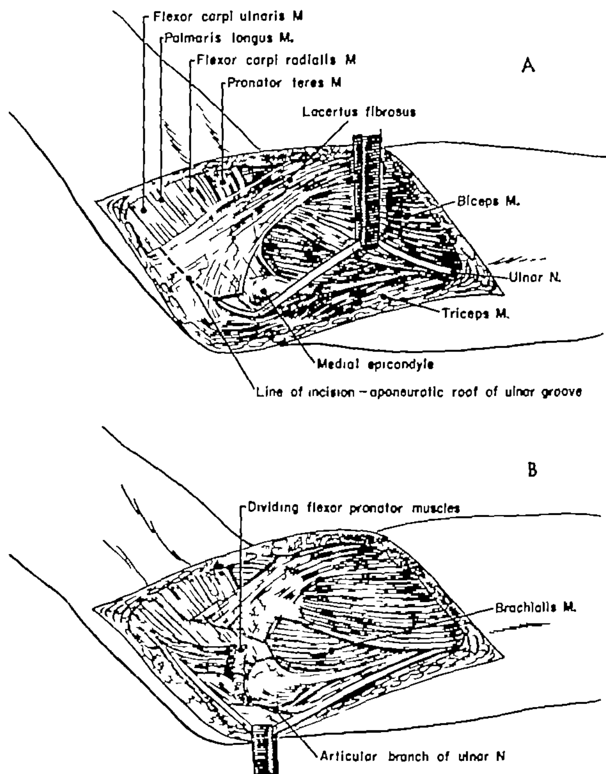


Fig 599 —Technique for transplanting ulnar nerve A, nerve exposed above the epicondylar groove by division of intermuscular septum between biceps and triceps muscles The lacertus fibrosus fascia and aponeurotic roof of the epicondylar groove are next divided. B ulnar nerve elevated and freed below by separating the two heads of the flexor carpi ulnaris and retracting the forearm flexor muscles medially The attachment of the flexor pronator muscle heads to the medial condyle of the humerus is then cut. It is often necessary to sacrifice the branch to the elbow joint. The flexor pronator muscles are turned back, exposing the median nerve

(continued)

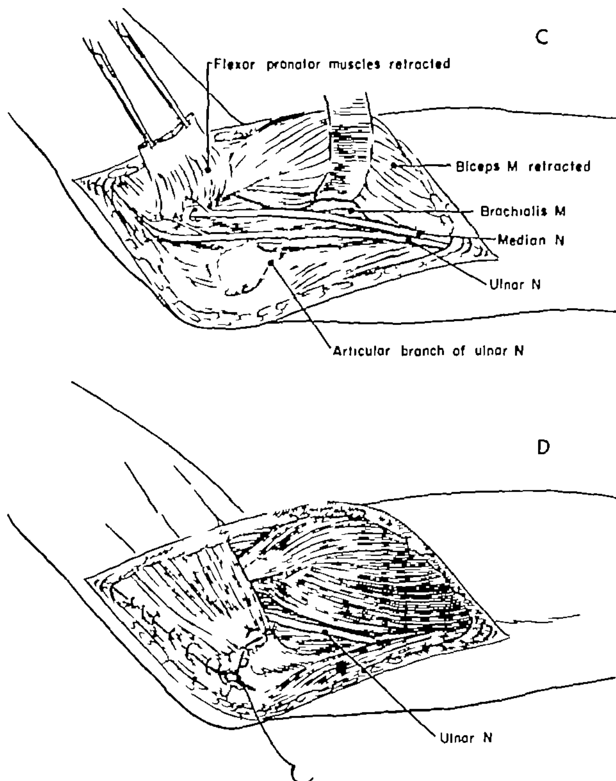


Fig 599 (cont) —C, ulnar nerve transposed in front of the humeral condyle and placed alongside the median nerve D severed muscle attachments are sutured with fine silk or stainless-steel wire. (Modified from Learmonth J R.: A technique for transplanting the ulnar nerve Surg., Gynec & Obst. 75 792, 1942.)

means of a turnbuckle hinged splint taking a month or so to straighten the limb This method has not often been satisfactory because stretching the nerve is likely to disrupt Schwann sheaths and lead to endoneurial fibrosis

NERVE GRAFTING BY FULL THICKNESS CABLE, OR PEDICLE GRAFTS —*Full Thickness Grafts* —Grafts for repair of larger nerves must usually be taken from a cadaver except in the rare case where another extremity requires simultaneous amputation. Homografts have never proved successful and even autografts are likely to fail in the repair of larger nerves because of inadequate circulation and central necrosis On the other hand, in bridging the defects of trunks of small diameter such as digital or facial nerve autografts of intercostal sural or lateral femoral cutaneous nerves have been very satisfactory

Cable Grafts —Cable grafts using a number of smaller nerves laid side by side and cemented in position with plasma glue by Tarlov s method are more likely to succeed than full-thickness grafts

Pedicle Grafts —Pedicle grafts as described by Selverstone have a limited use but have been more successful than any other method of bridging gaps in major nerves These can be utilized only with the sacrifice of a contiguous large nerve In Selverstone s case where there was an extensive gap in both the median and ulnar nerves at the elbow the proximal end of the median nerve was sutured to the nearby ulnar nerve which was then divided above in the axilla. As a result axons and longitudinal blood vessels from the median nerve grew into the upper decentralized segment of the ulnar nerve which was still supplied by its lateral vascular branches After a delay of several months when Tinel s sign showed regeneration of median axons throughout the upper ulnar segment this pedicle now supplied by newly formed longitudinal blood vessels was turned down and sutured to the lower end of the median nerve The patient thereby regained good function of the more important median innervation of the forearm and hand. A number of other successful examples of this ingenious procedure have been reported

The whole subject of nerve grafting is ably reviewed in the Medical Research Council monograph *Peripheral Nerve Injuries* edited by Seddon. Seddon reports many successes with cable grafts in bridging large defects in major nerves and even a few successes with main trunk autografts

POSTOPERATIVE CARE

After neurorrhaphy tension and disruption of the suture must be prevented by immobilization of neighboring joints in flexion but splints must be applied with extreme caution and only over the shortest possible period In the case of a high sciatic suture it is essential to apply a plaster spica to maintain extension of the hip as well as flexion of the knee Regeneration of severed nerves is of little value if a useful range of joint movement is sacrificed by overprolonged splinting Splinting of the wrist elbow or knee in acute flexion need never be maintained for longer than 2 weeks At the end of this period the joint can gradually be extended and the splint removed daily for passive flexion and massage Physiotherapy and full range of joint movement should be started within a month by this time tissue regeneration should safeguard the suture against disruption

During the prolonged course of reinnervation the patient must be taught to exercise the normal muscles and joints of the extremity as actively as possible Galvanic stimulation of paralyzed muscles will also do much to maintain their tone until voluntary movement returns Every possible means must be employed to maintain good function of joints and soft parts in order to have a useful extremity when nerve regeneration is completed

The course of reinnervation can be followed by downward extension of Tinel s sign the gradual return of sensation and

muscular contraction Shortening of chronaxy electromyographic evidence of loss of paralytic fibrillation the appearance of voluntary action potentials and the gradual disappearance of the reaction of degeneration will all precede the return of active movement. Full recovery will require about 6 months in the case of nerve suture at the wrist or ankle 1 year at the level of the elbow or knee and 18 months to 2 years when the suture has been performed in the axilla or upper thigh

TABLE 39 —MOTOR AND SENSORY RECOVERY AFTER SUTURE OF PERIPHERAL NERVES
(Statistics on Veterans of World War II Examined at Massachusetts General Hospital 3–6 Years after Injury)

INJURY	TOTAL NO	PERCENT OK OF MOTOR RECOVERY TO M3 STAGE*						PERCENTAGE SENSORY RECOVERY	
								S3‡	S2†
		Forearm Muscles	Intrinsic Muscles of Hand						
Median	55								
Upper arm injuries		93	31					52	93
Forearm injuries			54					39	69
Ulnar	66								
Upper arm injuries		82	63					39	69
Forearm injuries			57					30	82
		Wrist Extensors	Finger Extensors						
Radial	37	76	60					49	81
		Gastrocnemius Soleus		Peroneal	Tibialis anterior	Toe Extensors	Toe Flexors		
Sciatic	20	80		35	40	30	5	25	55
Tibial	16	83					50	17	89
Peroneal	35			20	29	23		20	81

* "Motor recovery to Stage 3" signifies fair recovery of contraction against resistance

† "Sensory recovery to Stage 2 signifies appreciation of pain and touch, sufficient to protect the extremity against injury More useful degrees of sensory recovery are listed in this category if accompanied by disagreeable over-response which may be a severe handicap.

‡ "Sensory recovery to Stage 3" indicates better recovery of pain and touch without over-response This permits good use of hand when finer qualities of sensory discrimination are not required.

RESULTS AFTER NERVE SUTURE

Certain nerves recover better than others. Sutures of the facial and radial nerves are likely to do particularly well those of the peroneal badly End results in 288 cases in veterans of World War II examined at the Massachusetts General Hospital are summarized in Table 39 Further statistics of much interest will be found in the Medical Research Council monograph previously cited

ORTHOPAEDIC MEASURES FOR CORRECTION OF PERSISTENT PARALYSIS

When a useful degree of motor recovery fails to take place the function of a paralyzed extremity can be improved greatly by a number of orthopaedic procedures These are well described by Campbell and by Bunnell Excellent functional results after irreparable radial nerve injury may be obtained by transferring wrist flexor tendons to the long extensors of the fingers and thumb

Irreparable ulnar nerve injuries may require no reconstructive surgery if the functional disability is mild The clawhand deformity which may occur can be improved by transfer of the flexor sublimis tendons to the lateral bands of the dorsal aponeurosis of the proximal interphalangeal joints

of the fourth and fifth fingers as described by Bunnell

For irreparable median nerve injuries function may be improved by transplanting the extensor carpi radialis brevis muscle to the flexor pollicis longus by attaching the flexor profundus tendons of the index and middle fingers to the functioning flexor profundus tendons of the ring and little fingers and by using the flexor carpi ulnaris to produce opposition of the thumb There is no truly satisfactory reconstructive surgery for combined complete ulnar and median lesions

Deltoid paralysis due to axillary nerve injury produces inability to abduct the arm Transplants of the trapezius muscle (Mayer) or of the triceps and short head of the biceps (Ober) (described in Campbell s *Operative Orthopedics*) can improve function in these cases

Irreparable injury to the musculocutaneous nerve results in inability to flex the elbow Advancing the origin of the forearm flexor muscles on the humerus (Steindler) is of benefit in these cases.

In the lower extremity injury of the femoral nerve results in paralysis of the quadriceps femoris muscle Despite such paralysis patients can learn to walk without apparatus (or at most with a cane) with an excellent gait. Transplant of a number of muscles in various combinations (biceps femoris semitendinosus sartorius and tensor fascia femoris) to the patella may improve extensor power and lessen the tendency for the knee to "give way"

Complete lesions of the sciatic nerve produce so much sensory deficit in the foot that amputation is often necessary eventually because of trophic ulceration Foot drop due to irreparable peroneal nerve palsy produces a steppage type of gait which may be corrected by wearing a short foot-drop brace Stabilization of the foot by ankle fusion by triple arthrodesis and anterior tenodesis or by transplant of the functioning posterior tibial tendon anteriorly through the interosseous membrane may enable the patient with foot drop to discard his brace with improvement in function of the extremity

PAINFUL SYNDROMES AFTER NERVE INJURY

A final complication of nerve injury that deserves mention is persistent pain. In lateral neuromas from penetrating wounds the burning discomfort of causalgia may become a source of intense suffering within a few hours or days This syndrome, so well described by Weir Mitchell, is characterized by diffuse burning pain and trophic disturbances with glossy skin and tapering fingers The pain is distinctly related to emotional disturbances and the victim prefers to remain alone in a closed room with the extremity protected by a moist towel, against changes in temperature and even drafts of air Experience has taught that neither resection of the neuroma nor any other operation on the injured nerve can be counted on to give effective relief In cases where the pain is relieved temporarily by stellate or lumbar sympathetic block, an appropriate sympathectomy can be relied on to give permanent relief (White Heroy and Goodman and Shumacker) In a review of the results in 62 veterans of World War II 2–7 years after injury it was found that a properly performed sympathectomy almost never failed to relieve true causalgic pain. In cases of high sciatic injury it is important to carry the resection of the sympathetic chain upward to include the first lumbar and the twelfth thoracic ganglia Failures occurred consistently after incomplete sympathetic denervation or periarterial stripping and in many instances when the neuroma was resected and the nerve sutured

Other types of pain and discomfort are common after nerve injury when there is lasting paralysis or when there is partial recovery after neurolysis or suture Usually the discomfort consists only of minor complaints of feeling of coldness paresthesia or spontaneous twinges of pain and these are not a serious problem On the other hand a few unfortunate individuals de-

velop a permanent state of sensitivity in their partially reinnervated skin which is best described as "over response" This is particularly incapacitating after injury to the median or tibial nerves when the sufferer is unable to grasp firmly with his hand or bear full weight in walking Occasionally the condition has improved after a secondary suture with better sensory recovery but often there is no solution except by recourse to anterolateral cordotomy Cutting the pain fibers in the spinal cord when done by an expert offers a good chance of success with little risk of serious complications in the case of sciatic and tibial injuries but at the Massachusetts General Hospital the results in the upper extremity have not been good enough to recommend such a radical procedure

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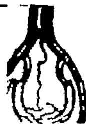
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40 Blood Vessel Injuries

ARTERIAL INJURY

MAJOR ARTERIAL injury accompanying fracture may be manifested by immediate hemorrhage or by arterial insufficiency and eventual loss of function or limb Arterial hemorrhage announces itself stridently and forces prompt and specific action on the part of the surgeon Traumatic arterial insufficiency is a result of injury sometimes of equal importance to the injury but is more subtle and may be unrecognized and neglected by the inattentive or uninformed physician

This chapter is designed as a guide to the recognition understanding, and treatment of vascular injuries Discussion is based on the thesis that the therapeutic ideal of restoration of normal anatomy and function should be applied just as vigorously in the treatment of major arterial injury as in the treatment of fractures

Natural History of Acute Arterial Occlusion

An understanding of the mechanism and sequelae of acute arterial insufficiency is necessary for its intelligent treatment After traumatic interruption of the major arterial supply to an extremity a predictable sequence of events takes place vasoconstriction vasodilation and the development of collateral circulation These 3 phases will be discussed in sequence

VASOCONSTRICTION —The body first responds with a spasm of the vessels in the affected part. This might be considered a protective mechanism against further hemorrhage It is partially a reflex constriction, mediated through the sympathetic nervous system and partly a traumatic arteriospasm intrinsic in the artery During this phase of vasoconstriction the circulation of the extremity is most strikingly diminished

VASODILATION —After several hours a second phase vasodilation takes place This condition represents an effort of the organism to increase the circulation to the part The point of occlusion in the main artery is bypassed by means of flow through the maximally dilated collateral channels

Nonoperative therapy in the early phases of an acute arterial occlusion is directed at minimizing the duration of the vasoconstriction and encouraging the dilatation of collateral Hemorrhagic shock, pain and cold—all are strong stimuli to vasoconstriction Therefore adequate blood replacement comfort and warmth are important to the early termination of the constrictive phase

Sympathetic blocks will diminish the reflex component of the vasospasm but

will not affect traumatic arteriospasm

During the very unstable period of circulatory readjustment thrombosis is taking place in the occluded artery If the patient is fortunate this thrombosis will extend from the point of occlusion proximally and distally to the first significant adjacent branch of the artery If he is unfortunate the thrombus will extend further usually in a distal direction it may occlude the entire major arterial tree to the part This latter sequence will interrupt inflowing collateral branches and thwart the efforts of the body to restore circulation The mobilization and reinforcement of blood-clotting mechanism accompanying trauma encourage the thrombosis Good collateral flow tends to limit it The two factors of greatest practical consideration in the development of extending thrombus are slow blood flow and the passage of time These are within control of the surgeon

Surgical procedures performed on extremities with precarious circulation tend to reinaugurate the "spastic" phase and interfere with circulation If the surgical procedure will of itself improve circulation, this disadvantage is overcome Ill considered operations may reverse the vasodilatation decrease collateral flow and result in further extension of thrombus

Development of Collateral Circulation —The third phase of gradual collateral hypertrophy begins following stabilization of thrombosis and vasodilatation The process takes place fairly rapidly over a period of 4–6 months and then more slowly over a period of years Collateral arteries parallel to the occlusion grow in response to the need for blood in the part and may especially in a young patient restore the circulation very nearly to normal Usually this collateral circulation never develops the capacity for flow possessed by the original vessel. Residual arterial insufficiency may be apparent as easy fatigue intermittent claudication cold intolerance or greater susceptibility to the circulatory complications of old age and arteriosclerosis

The Sequelae of Ischemia

Where the initial ischemia is not too severe and distal thrombosis has not been extensive the extremity survives the acute occlusion with only the functional impairments mentioned above Circulation may however be sufficiently impaired to result in ischemic death of tissue and gangrene

The likelihood of gangrene depends on the site of the arterial occlusion Table 40

TABLE 40*

Injured Artery	Total No. of Case	Percentage of Amputation
Subclavian	21	28 6
Axillary	74	43.2
Brachial		
Above profunda	97	55.7
Below profunda	209	25.8
Radial	99	5 1
Ulnar	69	1.5
Radial and ulnar	28	39.3
Common iliac	13	53.8
External iliac	30	46.7
Internal iliac	1	0 0
Common femoral	106	81 1
Superficial femoral	177	54.8
Deep femoral	27	0 0
Popliteal	502	72.5
Anterior tibial	129	8.5
Posterior tibial	265	13 6
Anterior and posterior tibial	91	69.2

Modified from DeBakey M. E., and Simeone F. A. Battle injuries of the arteries in World War II, Ann. Surg. 123 534 1946.

correlates amputation with site of arterial trauma in battle injuries and emphasizes the importance of restoring arterial continuity in injuries of such major arteries as the common femoral and popliteal, especially when their bifurcations have been destroyed Other factors such as associated injury in the area of impaired circulation and associated arteriosclerosis will affect limb survival in any given case

The previously described sequence of vascular responses continues in the presence of gangrene Dilatation of collateral circulation in this instance will reinforce doubtful circulation near the line of demarcation between dead and living tissue The adverse effect of early amputation on unstable circulation at the site of amputation must be kept in mind

The level of skin demarcation and the

level of muscle demarcation may be quite different. The nutrient arteries to muscle are frequently end-arteries so occlusion may result in death of the entire muscle Thus at midthigh amputation after thrombosis of common and superficial femoral arteries the entire anterior thigh musculature may be found necrotic beneath viable skin and subcutaneous tissue

In certain instances ischemia may not be severe enough to cause massive death of all tissues but may just affect the more vulnerable tissues such as nerve and muscle In a similar manner temporary circulatory arrest will injure the more vulnerable tissues Muscle will suffer necrosis after 6–8 hours of arrest of circulation. Where necrosis is not extensive patchy scarring with little interference with function will result. With extensive necrosis heavy dense contracting fibrous replacement of the muscle ensues Death of peripheral nerve will occur after 12–24 hours of ischemia Both sensory and motor deficits result Regeneration of both of these components is likely to be incomplete This combination of muscle necrosis and peripheral nerve injury may be seen in cases having surgical restoration of circulation after long periods of arrest secondary to trauma or embolus or where circulation has been drastically reduced for long periods of time by tight plaster or displaced bone Severe degrees of this injury are recognized as "Volkmann s contracture" (see the following chapter)

Therapy

Prompt recognition of major vascular injury is essential to its successful treatment Delay allows irreversible ischemic injury to take place and also encourages the propagation of intravascular thrombus Loss of limb because of improper treatment is seen too frequently and delay because of failure to determine the state of the arterial circulation is the most common fault

It is easy to miss major vascular injury if the physician is not constantly alert to its possibility Major degrees of extremity ischemia may be concealed by a general picture of shock and vasoconstriction. Extremities hidden in plaster casings and bandages may suffer serious circulatory impairment which will be missed by the incurious It is therefore important to assay vascular injury in the initial examination of the patient *and* to continue to check circulation, particularly through the early mobile phases of body readjustment to trauma.

Major arteries may suffer lacerations which demand repair but still may not have interruption of arterial flow nor show evidence of arterial insufficiency Such injuries are not always made apparent by hemorrhage Thus, a penetrating injury of the popliteal space with laceration of the popliteal artery may bring the patient to the hospital in shock but show no hematoma, loss of peripheral pulses or active bleeding at the time of admission. The nature of the injury should be suspected from the location of the wound and the evidence of past major blood loss and will be confirmed by exploration of the wound or hemorrhage on recovery from shock.

A closed fracture requiring a disproportionate amount of blood for correction of shock and showing excessive hematoma *should be suspected of being associated* with injury to a major blood vessel even if there is no loss of distal circulation. A mechanism of injury to a major artery in the region from displaced bone ends or from the original trauma can usually be visualized Excessive bleeding from a fracture site is occasionally a manifestation of a specific blood dyscrasia. Therefore bleeding time clotting time blood smear prothrombin time and observation of clot for fibrinolytic activity should be a part of the work up in such cases. If a bleeding defect is not present prompt surgical exploration and repair of the vessel should be performed Procrastination in these cases not only results in excessive blood loss and cumbersome hematoma but may lead to the development of false aneurysms or arteriovenous fistulas requiring surgery at

a later date under less favorable circum stances owing to scarring and fibrosis Restoration of normal arterial anatomy either by suture repair or by arterial graft should be the objective of surgery in false aneurysms or arteriovenous fistulas even when operated on late

Acute arterial insufficiency is seen after supracondylar elbow fractures fractures and dislocations of the knee and femoral shaft fractures and secondary to swelling within tight circular casings on the ex tremities It may of course accompany any injury to a major artery When arterial insufficiency appears in a traumatized ex tremity therapy should be active rather than expectant. The possibility of an ex *ternal cause such as a tight dressing or* plaster or displaced bone must first be ruled out and corrected if present If the circulation is not restored by these meas ures obstruction of the major artery within the limb is likely and surgical exploration and correction of the defect is indicated Such surgery is urgent and should not be deferred. Expectant therapy is allowable only when the insufficiency is very mild and when the injured vessel is small and so situated that it can be expected to have good collateral

It is important to localize the point of obstruction well There is danger of oper ating on the peripheral manifestation of a more proximal occlusion More than one fruitless fasciotomy has been performed in a calf where the primary disorder was fem oral artery occlusion from a fractured fem oral shaft The point of obstruction can usually be located by determining the level at which peripheral pulses disappear Care must be taken to be sure that the palpated pulse is synchronous with the patient s radial pulse since the examiner may be confused by feeling his own finger pulse This should be checked by the use of an oscillometer The most readily available one is an aneroid blood-pressure manom eter The cuff is inflated to a point just below systolic pressure at various levels on the extremity to determine the presence or absence of a pulse Arteriography is sel dom necessary and not without risk in these cases However the risk of arteriog raphy is less than the risk of expectant treatment and may be allowable in special circumstances

Exposing the vessel at the point of oc clusion may reveal any one of a number of causes for the obstruction It is most gratifying to find that after correction for a tense hematoma in the fascial compart ment of the artery or other extra arterial pathology good arterial flow is resumed The surgeon may however find a segment of artery where pulsations stop or are greatly diminished This may be reversible segmental arteriospasm without thrombo- sis but it should be looked on with the *greatest suspicion It is more likely* that there is a subintimal hematoma, thrombo- sis or other anatomical reason for the oc clusion If caused by arteriospasm the oc clusion will disappear with the exernal ap- plication of papavarine to the vessel The commercially available 1 cc ampule con taining 30 mg of papavarine may be used The wound must not be closed in the hope that the "spasm" will go away rather a persistent lesion should be explored by arterotomy and resection and a graft per formed if the artery is injured and throm bosed

There may be an obviously contused or lacerated segment A contused vessel must be excised at least 1 cm beyond obvious contusion because to leave traumatized endothelium is to invite thrombosis

A lacerated artery may be repaired by careful suture provided that the laceration is a sharp one without associated contu sion This is unusual in civilian practice except in the instance of a knife wound and the surgeon should never hesitate to resect questionable vessels and insert a blood vessel graft

Every fracture of an extremity should be considered to have an associated vascu lar injury until proved otherwise When the attending physician is in doubt com petent consultation must be sought prompt ly and without hesitation before loss of limb becomes inevitable If adequate facili

ties for reconstructive surgery are not available or the surgeon is inexperienced it is preferable to ligate and divide an in jured artery rather than attempt repair or put in an unsatisfactory graft. The patient should then be transferred to a hospital where adequate facilities and competent vascular surgeons are available.

Major arterial injury is an indication for surgical exploration Again it is essential that the surgeon be prepared to do re constructive surgery The goal is re-establishment of normal vascular anatomy

sure it can be a nightmare Pressure applied by an assistant, both proximal and distal to the source of bleeding will allow the surgeon to expose the blood vessels calmly and adequately instead of blindly clamping at the bleeding source which may do serious damage to both artery and concomitant vein

Care must be taken, in temporarily oc cluding vessels not to injure them Arterio-sclerotic vessels are particularly vulnerable because the fragile atheromatous layer is easily split. Serrated clamps (e g the

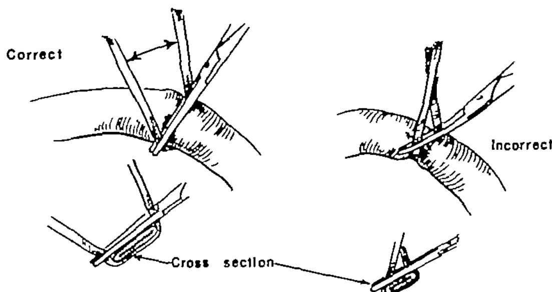


Fig 600 —Means of atraumatic control of major artery without the use of special instruments, using shoelace and a hemostat.

Operative Techniques

A few technical considerations are im portant

Exposure.—Reconstructive vascular surgery is impossible without wide exposure of the injured vessels Good exposure is obtained through conventional longitudinal incisions running parallel to the vessel and allowing extension for exposure of additional artery if need be These inci sions should be made initially without wasting time trying to work through the primary wound

Control of Bleeding —With good ex posure control of vessels proximal and distal to the injury is easy with bad expo-

Potts ductus clamp) are good for normal vessels but will damage heavy atheromatous vessels Bulldog clamps with weak springs will not injure such vessels. A modified Bethune lung tourniquet clamp or a Crafoord clamp are good for control of very large arteries like the aorta Special instruments are not essential how ever Excellent atraumatic control can be secured by means of a tape passed beneath the vessel drawn tight and clamped as shown in Figure 600

Blood Vessel Suture.—Two general principles are of great importance in blood vessel suture

1 *Intact uninjured endothelium must* be presented to the blood stream to avoid

thrombosis Injured tissue in contact with the blood stream will cause the formation of thrombus For this reason great care should be taken not to abrade or pinch the endothelium with forceps during performance of a blood vessel suture The cut edges of the blood vessel must be everted to keep the injured tissue from the blood stream.

2. The suture line must not compromise the lumen of the artery since this will slow the flow of blood which in turn encourages *thrombosis* *To avoid such damage requires* the careful placement of fine stitches not more than 1 mm from the edge of the vessel and the use of atraumatic needles with fine suture material 5-0 to 6-0 Care must be taken in the placement and tying of running sutures so as to avoid "puckering up a vessel on the suture and thus narrowing it

Contrary to previous teachings extensive excision of adventitia at the site of a vascular suture line is unnecessary and actually injurious because it seriously disturbs the circulation of the vessel wall This is especially true in sclerotic vessels where the adventitia is important to vessel strength Rupture of the artery used to be a common complication of periarterial sympathectomy in cases where adventitia was extensively excised

Where major arteries must be divided closure by suturing the ends is preferable to using a ligature (1) because suturing does not require the generous cuff that ligation does and consequently it is not so wasteful of important vessel length and collateral branches and (2) because this method is more secure and avoids the possibility of secondary hemorrhage due to slough of the vessel at the site of ligature or cutting through or breakage of a ligature Suture closure of an artery should be performed next to a branch as shown in Figure 601 An arterial laceration is closed with a running everting suture through the full thickness of the vessel wall

In normal elastic artery anastomosis can be performed by a modification of the original Carrel technique Everting mattress stay sutures are placed first Traction is maintained on the stay sutures to stretch the margin of the vessel during the placement of a running suture between them in order to keep from narrowing the lumen The running suture can be an over and over Carrel stitch or a running everting mattress suture depending on the preference of the surgeon and the ease with which the vessel edges evert. Rigid atheromatous arteries smaller than the common iliac are best anastomosed with interrupted everting mattress sutures (Fig 602) The more difficult sutures in the atheroma are placed first

In small arteries where there is sufficient length as in some simple transections and in all grafts an oblique anastomosis (Fig 603) is preferable to the standard end to-end suture This is a quick and simple method and avoids constriction at

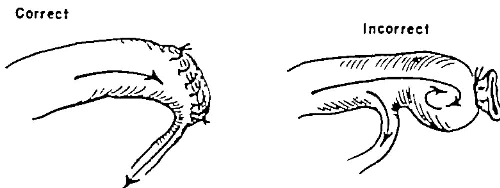


Fig 601 —Suture closure of a major artery next to a branch avoids possible necrosis distal to a ligature and formation of a thrombus in the blind segment.

the suture line which is a primary reason for failure

Gentle and meticulous technique with complete control of all bleeding points is necessary for good results Hematomas favor sepsis and also result in necrosis of the grafts.

Blood vessel anastomoses are not diffi-

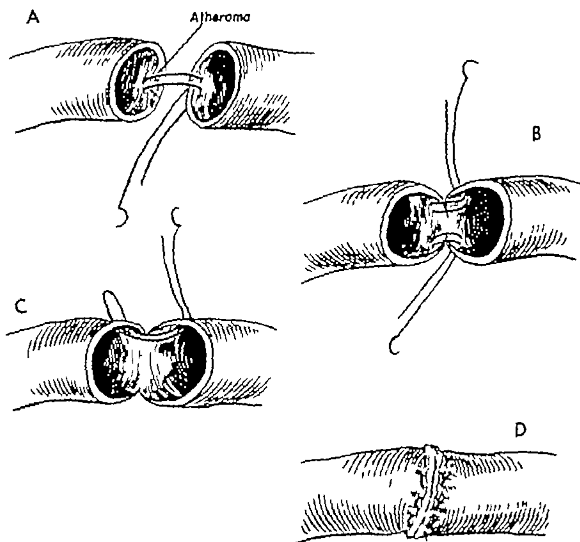


Fig. 602.—End-to-end anastomosis in a rigid arteriosclerotic vessel is accomplished with interrupted everting mattress sutures placed first in the more rigid portions of the vessel.

cult to perform but are different enough from everyday "cutting and sewing" to require practice for their adequate performance A patient is not a proper subject on which to learn It is strongly recommended that the interested surgeon secure experience with vessel anastomoses in an experimental animal. Successful experience with anastomoses performed on a dog carotid and a dog aorta can be expected to spell the difference between success and failure in the first clinical anastomosis performed Much valuable experience can be gained in working with autopsy material, especially with sclerotic vessels

GRAFTS —At the present time the most satisfactory graft for arteries smaller than the aorta is an arterial homograft preserved either by freezing or by freeze-drying. However if an artery bank is not available venous autografts taken from the saphenous vein are satisfactory for an artery less than 8 mm in diameter Venous grafts must of course be reversed so that the valves will not interfere with flow It is inadvisable to use the femoral vein as a

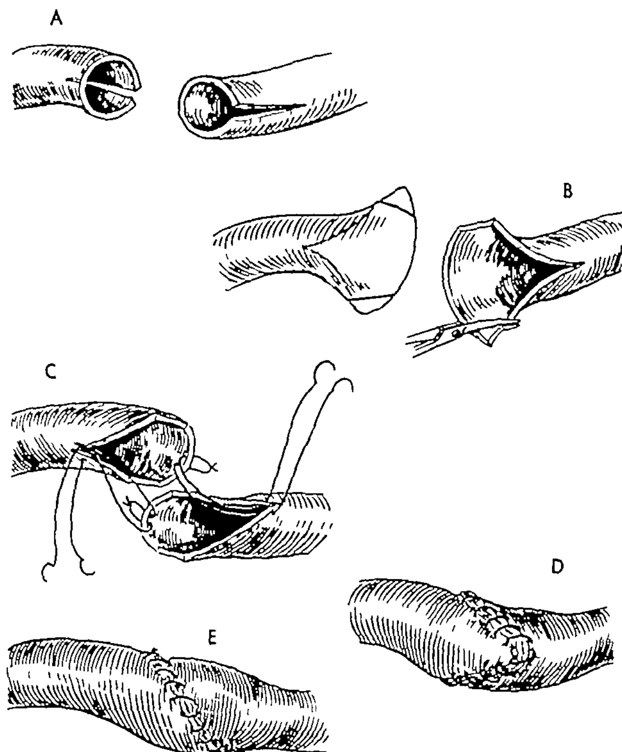


Fig. 603 —Where there is sufficient vessel length as with a graft the oblique anastomosis shown here is preferred.

graft for a femoral artery because the vein is much larger than the artery Also its use may lead to severe venous insufficiency especially if the saphenous vein has been injured

Grafts must be inserted under some

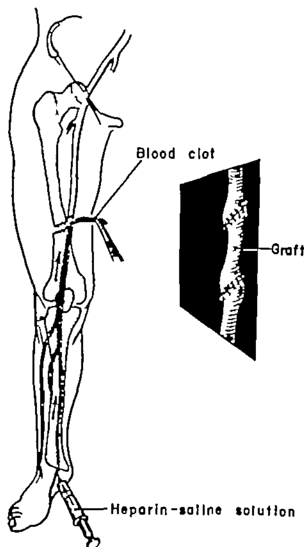


Fig 604 —A distal thrombus may be retrogradely flushed out with warm heparin-saline solution (10 mg./100 cc.)

tension otherwise the vessel will become tortuous when the clamps are released It is well to instill dilute heparin saline solution (10 mg /100 cc) in the graft and 10 cc. intra arterially beyond each of the controlling clamps during the procedure in order to avoid thrombosis and air embolus

Distal Thrombosis —As the interval between the initial arterial occlusion and operation approaches 12 hours clot propagation down the vessel becomes an increasingly serious problem. After this period of time some degree of distal thrombosis is the rule Distal thrombosis probably accounts for the majority of failures in arterial embolectomy and is most familiar to surgeons in this connection

Removal of a distal thrombus is essential to the success of any procedure to re-establish arterial flow since distal obstruction to flow will result in rapid thrombosis at the site of a proximal repair arteriotomy or graft It is possible to remove even an extensive distal thrombus and every effort should be made to do so

If the distal thrombus is short it is possible to withdraw it through the original arteriotomy Here it is important not to apply a controlling clamp on the distal vessel until the clot has been extracted and back bleeding obtained, since it is possible to break the clot by rough handling and have the distal fragment pass down the vessel. When the distal end of the extracted thrombus is not smooth and blunt it is probable that clot remains in the vessel and that other measures will be required for its removal. The same may be true if distal pulses do not appear after flow is re-established The most effective means of removing such a distal clot is to flush it out retrogradely with warm heparin saline solution (50 mg /100 cc) injected into the artery at a point beyond the farthermost extension of clot. The site of injection of the solution will vary with the location of the thrombus but a clot may be successfully removed from the smaller vessels of the calf by flushing from the posterior tibial artery at the ankle (Fig 604) and from forearm vessels by flushing from the radial artery at the wrist. Other arteriotomies along the course of the vessel are used as required The heparin-saline solution is injected with a large syringe through a No 15 or 16 needle and the vessel is not interrupted following injection

Sepsis and Secondary Hemorrhage —Sepsis involving a ligature of a major

vessel was a familiar and much feared complication of amputation in the days before asepsis but for a long time it has been so uncommon in civilian surgery as to be almost forgotten With the great in crease in the number of operations involv ing arterial grafts sepsis and major sec ondary hemorrhage have again become a matter of major concern

Tissue devoid of circulation is helpless before infection The arterial graft of course is dead tissue and as such is ex quisitely vulnerable Once a graft is in fected rupture and hemorrhage are almost inevitable Such weakness is intrinsic in a vascular graft a fact which stresses the importance of rigid aseptic technique

Certain avoidable practices weaken the resistance of a vessel to infection and may increase the likelihood of secondary hem orrhage if sepsis should occur The arterial ligature devascularizes tissue beyond the tie. Stripping adventitia destroys the vasa vasorum. An arterial suture line placed too tightly compromises the circulation of the vessel wall In all these instances sepsis may result in slough of vessel wall and major hemorrhage

Secondary hemorrhage usually occurs from 1 to 2 weeks postoperatively The con trol of major secondary hemorrhage poses a formidable problem The surest method of control is proximal ligation of the artery through a new incision and a clean field This is sometimes not possible and usually causes a more critical embarrassment of arterial circulation than there would be if the vessel were controlled at the point of hemorrhage Control of the hemorrhage at its source allows less interference with cir culation but leaves open the possibility of further secondary hemorrhage If control is attempted through the septic field at the site of the hemorrhage any involved graft must be excised and the artery must be closed with fine sutures placed with mini mal tension and great care so as not to strangulate tissue Where secondary hem orrhage occurs from the side wall of an artery the vessels should be divided and the ends sutured This arterial suture line should be isolated from the body of the wound by covering it with a flap of well vascularized tissue and the body of the wound should be drained Full dosage of an antibiotic to which the organism is sen sitive is indicated Because of the serious ness of this complication and since no operation is absolutely aseptic prophylac tic antibiotics should be used However the most effective preventive therapy is scrupulously careful surgical technique

ANTICOAGULANTS —At the time of sur gery after wound hemostasis has been se cured the local intravascular injection of heparin as described above is useful Sys temic use of anticoagulants in the post operative period however is contraindi cated because of the extreme frequency of major hemorrhagic complications If good flow is obtained through vessels properly sutured and untraumatized thrombosis will not occur If there is poor flow through an improperly performed anastomosis or a traumatized vessel thrombosis will be in evitable—whether or not anticoagulants are used

SYMPATHETIC BLOCKS —Paravertebral sympathetic blocks with procaine or simi lar drugs may be used in the therapy of acute ischemia but should never be per sisted in as a definitive treatment. Blocks should always be considered ancillary to restoration of normal vascular anatomy Lumbar sympathectomy is contraindicated in the acute phase of arterial insufficiency Such a major operation does more harm than good because it reinaugurates trau matic arteriospasm and encourages throm bosis

VENOUS INJURY

Although restoration of arterial function is of primary concern after trauma to an extremity the consequences of venous in jury direct or indirect must not be over looked The effect may be due to local damage such as contusion or tearing of the vessel wall itself or may be of a more general nature and result from the hypo- tension accompanying the shock of injury

In general local repair of a lacerated vein should not be attempted because thrombosis at the site of injury is likely to develop The vena cava and the larger vessels of the neck, axillae and pelvis provide an exception to this principle because in these areas the channel is large and blood flow from divergent sources is present. The increased likelihood of thrombosis in a vein requires that repair be performed with scrupulous attention to the previously mentioned principles of blood vessel suture All the smaller veins of the extremities themselves can be ligated with little serious disturbance of limb circulation and even the inferior vena cava below the renal veins can be sacrificed if its repair is impossible. Distal venous stasis and edema secondary to ligature can be controlled by elevation and elastic support

By far the most important venous disorder associated with trauma is venous thrombosis with secondary embolism Most injuries of any degree provide two of the prime requisites for thrombus formation—namely slowing of the blood flow and roughening of an area of venous intima somewhere in the body Although many emboli find their origin from venous thrombi at the site of injury itself it has been well demonstrated that thrombi may develop in veins distant from the site of trauma The most common location for such spontaneous venous thrombosis to occur is in the deep veins of the legs where it produces the familiar clinical entity of thrombophlebitis

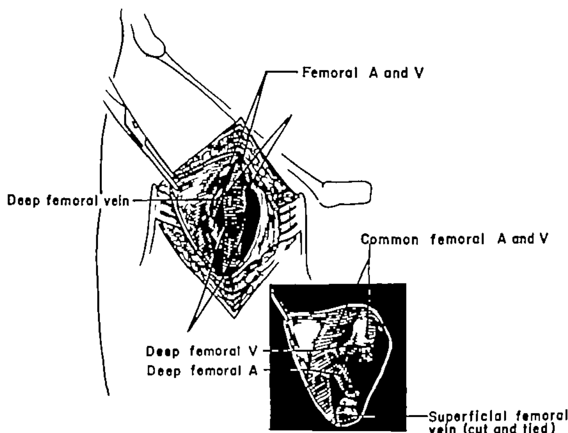


Fig 605 —Superficial femoral vein ligation The origin of the deep femoral vein is visualized and superficial femoral vein divided and ligated at this point. Care is taken to leave no blind segment of superficial femoral vein from which a thrombus might arise

The diagnosis of phlebothrombosis thrombophlebitis or even pulmonary embolism in the injured is often difficult. Local signs may be lacking or may be obscured by casts traction and other forms of therapy to the injured part. Pleuritic pain or hemoptysis is most difficult to as-

sess in the presence of a chest wall or lung injury In the elderly immobilized patient particularly venous thrombosis must ever be suspected and any patient exhibiting an unexplained simultaneous elevation in temperature pulse and respiration should be regarded with concern At the Massachusetts General Hospital from 65 to 80 per cent of all massive emboli occurred in tory as early as possible Compression support to the lower extremities by means of elastic stockings or wide Ace bandages speeds deep venous flow particularly in the patient with superficial varices and lessens the chance of thrombus formation Prophylactic anticoagulants may aggravate bleeding in traumatic injuries and are rarely indicated

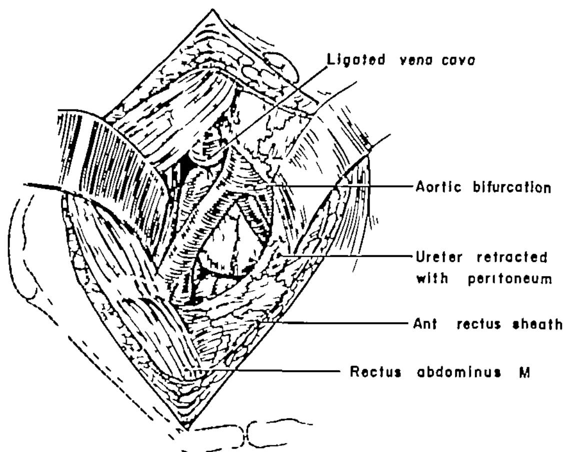


Fig. 606 —Inferior vena cava ligation The bifurcation of the vena cava is exposed through an extraperitoneal approach, the rectus muscle being retracted laterally and the peritoneum and ureter medially The vena cava is doubly ligated in continuity with heavy nonabsorbable ligatures just above the bifurcation

the group of patients without premonitory signs or symptoms *of venous thrombosis* Individuals suffering fracture in the lower extremities particularly about the hip area contributed greatly to this group

It becomes obvious that measures aimed at preventing peripheral thrombosis are of special value in the injured Restoration of blood volume and blood pressure by proper replacement is a first essential Activity in bed, both passive and active should be encouraged. Patients should become ambula

In the event of a recognizable thrombophlebitis *or a sublethal pulmonary embolus* bilateral femoral vein interruption should be performed In an autopsy series studied at the Massachusetts General Hospital, 98 per cent of pulmonary emboli originated in the leg veins Although interruption of the superficial or common femoral vein has not eliminated subsequent emboli completely it remains the treatment of choice in this particular group of patients The femoral vein should always

be divided and ligated rather than ligated in continuity It should always be ligated flush with the origin of the profunda femoris vein in the case of a superficial femoral vein ligation (Fig 605) or flush with a major branch in the case of common femoral vein ligation The common femoral vein must not be interrupted above the saphenofemoral junction because of despite femoral vein ligation and anticoagulant therapy or where pulmonary embolism arises from an iliac thrombophlebitis obviously beyond the reach of a femoral approach A patient with phlebitis and edema rising above the knee can be presumed to have iliac vein thrombosis. If the patient is seen within 48 hours of the beginning of thigh and groin edema, com

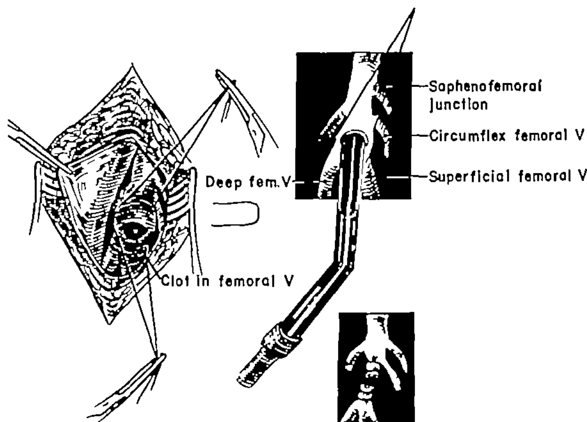


Fig 607 —Thrombectomy and common femoral vein ligation The common femoral vein is exposed at the groin The deep femoral superficial femoral and circumflex femoral veins are identified and control is established by passing two ligatures beneath the vein as shown. The presence of thrombus is confirmed by opening the vein and the thrombus is extracted using a glass sucker tip The common femoral vein is then divided and ligated adjacent to a major branch taking care not to interfere with flow from the saphenous vein and not to leave a blind segment of vein at the point of ligature

the severe venous obstruction that may result

Where the original injury permits anticoagulant therapy with Dicumerol® or related drugs should be added to venous interruption in the treatment and should be continued until the patient is well mobilized.

Vena cava ligation (Fig 606) is indicated where pulmonary embolism occurs mon femoral vein interruption with thrombectomy (Fig 607) is recommended After this period the thrombus becomes too adherent to remove and the foregoing indications for vena cava ligation apply

In summary traumatic arterial injury will be manifested by either bleeding or arterial insufficiency Prompt recognition and treatment are essential in both condi

tions. Modern techniques of vascular surgery allow the primary mechanical defect to be corrected in almost all cases The goal of therapy should always be restoration of normal vascular anatomy

Clean lacerations of the great veins may be repaired In general injuries of veins of the extremities should be treated by ligation next to a major branch because of the danger of thrombosis and embolization. Venous ligation is the treatment of choice in established thromboembolic disease.

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Volkmann's Contracture

VOLKMANN'S CONTRACTURE of muscle is a clinical tragedy No matter how expertly a fracture is treated, the beneficial effects are nullified if muscle contracture develops. The preceding chapter gives detailed consideration to the management of blood vessel injuries, which frequently are the basis for muscle ischemia. It is fitting to add a clinical consideration of Volkmann s syndrome and a review of our present knowledge about the syndrome

NATURE OF THE PROCESS

Classical Volkmann s ischemic contracture is the result of massive infarction of the muscles of the forearm subsequent to fractures of the elbow joint humerus or forearm bones It has become a vanishing clinical entity since Volkmann and Leser emphasized its relationship to impaired circulation. The fundamentally ischemic cause of the process is now accepted and the histological picture of muscle infarction has been established as the ultimate criterion for diagnosis A similar process has been shown to involve the leg muscles subsequent to injuries of the femur knee joint or tibia and ischemic changes of the intrinsic muscles of the hand have been described

Evidence of damage to nerves of the extremities is frequently part of Volkmann s syndrome—so much so that the muscular changes were originally thought to be secondary to denervation alone Three lines of observation however have shown that denervation is not the cause (1) histologically the degeneration of muscle which follows denervation is a diffuse fibrosis rather than an infarction (2) Volkmann s contracture may occur without demonstrable damage to nerves and (3) characteristic lesions of nerves are produced by the same ischemic processes which cause muscle infarction. The current concept then, is that ischemia is the cause of the lesions of muscle and nerve and that such ischemia is not sufficiently complete to cause gangrene of all tissues but selectively affects those tissues having a special structure and a metabolism which are most sensitive to circulatory impairment.

The infarcted muscle usually becomes a sterile sequestrum surrounded by fibrous tissue which cannot be penetrated by peripheral regenerating muscle fibers. The sequestrum may ultimately calcify or become infected but most commonly it is slowly replaced by dense scar with fibrotic atrophy and complete fixation of the forearm structures contiguous to it. The characteristic clawhand with stiffening of the small joints is due partly to contracture in the forearm and partly to disuse. When nerves are also damaged the sensory loss

and further degenerative processes of muscle render the extremity painful and useless.

It has been difficult to produce the Volkmann process in experimental animals The laboratory evidence which exists however forms the basis for preventive treatment.

MECHANISMS OF ISCHEMIA

Edema

On theoretical grounds ischemia of tissue cells occurs whenever stasis sufficient to interfere with exchange of oxygen and cellular metabolites is found It follows that edema and extravasation of blood *in a confined space* will produce a progressive ischemia with impairment of capillary venous and arterial circulations as pressure increases The tissue ischemia of edema is illustrated clinically in instances of tight bandages casings or splints applied to extremities The pressure that may exist in a confined space following injury is obvious when the fascia is split over such spaces as the flexor muscle compartment of the forearm or the anterior tibial or gastrocnemius compartments of the leg The fascial confinement of muscle is favorable to the production of ischemia of edematous origin.

Venous and Lymphatic Obstruction

Acute venous obstruction causes a transient ischemia by blocking the outflow of blood from an extremity By rapid dilatation, the collateral venous pathways are sufficient to provide adequate flow centrally unless most of the major veins are obstructed completely and simultaneously However before the collateral channels can dilate effectively sudden extensive venous obstruction may cause an ischemia sufficient to damage muscle Lymphatic obstruction has a similar effect but to a milder degree When venous and lymphatic obstruction occur together the edema is intensified and the degree of ischemia is augmented It is often difficult to distinguish between the two components but there is much evidence that acute venous obstruction by this mechanism may be a significant factor in the development of Volkmann s contracture

The acute mechanism is distinguished from chronic or partial venous or lymphatic obstruction wherein the effects of stasis are greatest in the skin and subcutaneous tissues and only manifested as cramps and fatigue by the muscles

Arterial Obstruction

As stated in the preceding chapter the susceptibility of tissues to infarction appears to depend on the pattern of arterial supply and on the metabolic demands of the specific tissue Anatomical studies of the forearm and lower leg muscles show that such areas are susceptible to infarction in the event of damage to a single major artery However experimentally it is difficult to produce a pure muscle infarct by isolated arterial ligation The results are either (*a*) transient with rapid recovery or (*b*) total producing gangrene of all tissues distal to the ligation Concomitant tourniquets and muscle incisions bear little relationship to the clinical Volkmann s syndrome but Brooks produced infarction and contracture in dogs by venous ligation in conjunction with arterial obstruction of varying duration Indeed his work threw the weight of conviction toward venous obstruction as the special determining feature of Volkmann s contracture

Traumatic Vasospasm

Recent understanding of the physiological behavior of arteries has emphasized that arterial vasospasm which involves the major artery *and its collaterals* is an outstanding component of the initial phase of most ischemic contractures The two vasospastic patterns which have been demonstrated are discussed in the preceding chapter Resection of a segment of damaged artery will interrupt the starting point of

either mechanism whereas procaine injections of the sympathetic nerves will affect the spinal reflex mechanism alone There is little doubt that the concept of arterial injury with extensive vasospasm helps to explain the varied circumstances under which Volkmann s contracture develops

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THROMBOSIS

Thrombosis of arteries or veins with propagation of the clot is not a conspicuous feature of Volkmann s syndrome in the acute phase Extensive thrombosis is more commonly associated with frank gangrene Histological study of the small vessels has shown some stasis and clumping of cells in the venules but no widespread thrombosis However in any vascular injury the possibility of thrombosis as an exceptional factor must not be neglected.

ALTERED MUSCLE METABOLISM

The usual greenish color of the muscle infarct and the sterile inflammatory process that accompanies it have stimulated a review of studies on muscle regeneration and the chemical changes that follow ischemia. After simple injury new muscle buds from each side of the damaged area show strong tendencies to bridge small gaps and to re-establish continuity of the fiber The success of regeneration appears to depend on the viability of the sarcolemmal sheath and nuclei. By contrast, the muscle infarct contains no viable cells and incites a peripheral inflammatory and fibrous reaction which cannot be penetrated by new muscle buds In mild forms the infarctions may be spotty through a muscle belly with sufficient viable areas between to permit recovery of function but the massive infarct is surrounded by an inflammatory and fibrous reaction before muscle regeneration becomes active Although chemical studies of normal muscle metabolism and changes following ischemia have been reported there is little information regarding the constitution of infarcted muscle The irritative feature the hardness of the muscle and the rapid contracture have been compared to rigor mortis and contrasted with the flaccidity of muscle in a gangrenous extremity There is a need for greater understanding of the chemical processes involved.

RECOGNITION OF IMPENDING VOLKMANN'S CONTRACTURE

Although current knowledge may be incomplete it is advisable to place the preventive management of impending Volkmann s contracture within the reach of all surgeons Constant suspicion early recognition and active therapy directed against the mechanisms outlined above form the basis for successful care

CLINICAL FEATURES

Volkmann s contracture most frequently follows supracondylar fracture of the humerus in children The characteristic displacement of the bone angulates the brachial artery against the upper fragment and may damage the artery's wall The artery may be caught between the fragments or ruptured The fascia of the biceps muscle spreads to form a tight roof to the antecubital space and most of the venous and lymphatic channels of the forearm cross the space anteriorly After reduction the position of fragments is best maintained by flexion of the elbow and plaster splints All of the initiating components of ischemia are present in some degree arterial injury with diffuse reflex vasospasm venous obstruction and local swelling in a confined space further confined by the position of flexion and by pressure externally applied

The earliest clinical signs of impending Volkmann s contracture in the hand are those of impaired circulation There is pallor coldness, and evidence of ischemia beneath the fingernails followed by swelling The radial pulse is usually absent although a pulse has been demonstrable in a few cases in which the contracture developed later The clinical signs are rapidly progressive Muscle ischemia first becomes

apparent by an inability to extend the fingers actively and by resistance to passive extension Severe pain usually accompanies the syndrome particularly if the muscles are put under tension If there is also damage to the nerves however pain may be virtually absent When neglected the process runs an increasingly severe course for a few days after which there may be some return of the radial pulse and apparent improvement in the circulatory status of the hand. But the damage to muscle has been done and the progressive fixation and contracture continue Ultimately the fingers can only be extended when the wrist is flexed, the forearm tissues are hard and wasted, and the skin of the hand is thin and atrophic. There may eventually be almost complete regeneration of nerve but paresthesias and hypersensitivity often persist

Volkmann s contracture also occurs following fractures of both bones of the forearm or around the elbow joint The clinical features are the same as described above It is worth remembering that external injury in the absence of fracture has caused some cases and that *any* series of events which sets off the mechanisms of ischemia is essentially dangerous

The same sequence of events applies to the lower leg. The femoral and popliteal arteries are even more essential to the viability of the lower leg than the brachial artery is to the arm Injury to the anterior tibial artery may produce selective necrosis of the muscles of the anterior tibial compartment, and contractures that involve the gastrocnemius and produce a clawfoot are more disabling. In cases of fractured femur the site of arterial injury may be in the thigh and the signs of ischemia be evident only in the calf Contractures are reported less frequently in the leg than in the arm either because total ischemia with gangrene is more prevalent or because the ultimate disability is not so dramatic.

Minor degrees of ischemia probably occur more often than is recognized There is no certain way to determine the degree of ischemia compatible with recovery of function The time of onset may be during manipulative reduction rather than at the time of fracture or a few days after injury Experienced surgeons have had the process develop under their eyes when they thought the danger period had passed Injured patients particularly children are unable to give adequate subjective warning through their symptoms The doctor must make the observations and act on them with conviction if tragedy is to be avoided

Identification of Impending Contracture

Suspicion that ischemic contracture may develop is based on repeated clinical examinations The initial examination is the most important and must include evaluation of the following

1 The over all circulatory status of the patient

2 The type of injury to the extremity using roentgenograms when appropriate

3 The circulatory status of the injured extremity compared with that of the contralateral one

4 The presence or absence of accompanying neurological deficit

The color temperature nail bed circulation edema venous engorgement sensation and active and passive motion of the fingers or toes must be observed and recorded The radial and ulnar pulses must be palpated and compared Oscillometry may be useful The same examinations should be made after each manipulation or change in position of the extremity and frequent (at least hourly) record of finger tip color and function and of the radial pulse should be made for 48 hours after definitive therapy of the injury The state of the peripheral circulation is more significant than the presence or absence of a palpable radial pulse

MANAGEMENT OF IMPENDING CONTRACTURE

Reduction of the Fracture

If the foregoing signs of ischemia are noted and if the bone is broken the frac

ture should be reduced by manipulation Griffiths states that many contractures follow manipulative reduction while others believe that reduction often releases an artery that is impinged by one of the fragments In either case if ischemia persists or begins all external pressure is removed and the extremity is placed in a position of partial extension and elevation. Repeated manipulations are inadvisable if the first one is thorough

Nonoperative Measures Directed against Vasospasm

Papaverine is used to relax the spastic muscle of the arterial wall It may be administered intravenously but it does not appear to have more than temporary value Procaine block of the sympathetic ganglia has occasionally relieved the ischemia, but this also must be repeated for sustained effect. Both types of treatment often show temporary and confusing effects. Their danger is that more active treatment will be unduly postponed. Unless the return of a good circulation is prompt unequivocal, and sustained through 48 hours operation should be undertaken directly Severe ischemia has produced irreversible necrosis of muscle in 6–8 hours. Although operations done at longer intervals have been followed by good recovery procrastination is unsafe

Operative Management

The aims of operation are to release pressure in confined tissue compartments to relieve venous obstruction, to relieve arterial obstruction and vasospasm, and to identify gross injury to nerves.

Efforts to obtain accurate reduction of the fracture are of secondary importance and must be limited to those which clearly help the circulatory status Since it is imperative to preserve all collateral circulation internal fixation of the fracture must not entail additional dissection and generally should be avoided

Past experience has shown that extensive splitting of the fascia over the muscle bellies and antecubital or popliteal spaces often relieves the ischemia. This simple maneuver releases pressure and minimizes the harmful effects of edema and venous obstruction. It is obvious that attempts to close such a wound primarily will reproduce pressure and ischemia. The deep fascia must not be closed and skin closure done without tension In a few days when the swelling has subsided secondary skin closure may be done easily in accordance with the principles developed in World War II.

Although the circulation may improve after splitting the fascia the integrity of the arterial flow must be assured In the preceding chapter the recognition and management of arterial injury and vasospasm are treated in detail and the reader should study that material carefully It is worth repeating that the arterial injury may be hard to find, that the surgeon must not rest until a good peripheral circulation is obtained, and that present methods of direct repair or grafting warrant trial

In the arm recovery of the circulation after resection of the grossly damaged segment of the brachial artery has been good. Where no gross arterial lesion is seen and no improvement follows exposure of it and application of heat or procaine resection of the area where spasm begins has also proved successful. In the lower extremity the use of an arterial graft should be considered much more seriously Articles which deal specifically with impending Volkmann's syndrome do not include considerations of grafting or primary repair but recent experience with war wounds and with other forms of arterial insufficiency indicate that grafting is advisable in the lower extremity unless the peripheral circulation is excellent after resection of a damaged segment.

If gross damage to major nerves is identified primary repair should not be attempted since it is very difficult to determine the extent of injury Three or 4 weeks later there will be accurate demarcation and a complete resection of all damaged

nerve with suture can be done Ischemic lesions of nerves are not grossly identifiable and they show a high degree of ultimate recovery If careful study shows no evidence of regeneration after a month exploration of the nerves should be undertaken.

MANAGEMENT OF ESTABLISHED MUSCLE ISCHEMIA

Every doctor is concerned with the prevention of Volkmann's contracture Unfortunately recognition and therapy have occasionally been so delayed that large clinics continue to report established cases

The Established Case Seen Early

There is no way to determine accurately how much damage is done in the early stages of any given case Therefore even though pain, a swollen hard forearm nerve deficit, and inflexibility of the hand predict that muscle necrosis has occurred it is best to operate up to 48 hours after onset. Experience with peripheral vascular disease indicates that unanticipated recovery of muscle may occur if good blood flow is re-established in the major arteries Operation is harmful in cases of mild ischemia but in the severe extensive case there is little to be lost and possibly much to be gained.

Operations done 3 days or more after onset have not been successful Because an extensive infarct ultimately fixes the adjacent tissues together it is tempting to excise the infarct in order to reduce the eventual restricting scar to a minimum Unfortunately *neither the extent of necrosis nor of ultimate regeneration can be gauged with sufficient accuracy to merit such a procedure* and the dangers of introducing infection or reinaugurating ischemic mechanisms are real. Consequently it is best to use measures designed to minimize contracture and maintain maximal function of joints Such measures consist of exercises physiotherapy external splints and traction devices

The Mild Established Case

Ischemic changes may be so mild and spotty through the muscle bellies that evidence of contracture is not clear until the fracture has healed and the slow restriction of finger motion arouses suspicion of trouble In such instances it has been customary to use physiotherapy and finger traction to regain range of motion Any reduction in the vigor of treatment may be followed by recurrence of the hand's contraction In this event after long trial with such treatment it may be wise to *liberate the muscles from scar at operation* or to lengthen the flexor tendons in order to regain function

The Severe Established Case

If established contracture is neglected the effects of disuse are added to those of the basic process They are atrophy of the skin osteoporosis degeneration of the joints contraction of joint capsules vasomotor instability hyperesthesia and loss of mass of normal muscles Nerve deficit is quite variable Complete evaluation of the problem requires repeated examination during the course of intensive physiotherapy exercises appropriate splinting and constant gentle finger traction which is designed to overcome insofar as possible the effects of disuse Maximum improvement must be gained from such measures before corrective or reconstructive operations are considered and these measures may require months of faithful work Repeated electromyographic records studies of muscle response to electrical stimulation and detailed neurological evaluations should be made in order to assess the potential function available in the damaged muscles and nerves The continued growth of bones in children effectively increases the deformity The management of each case presents an individual problem

The operations designed to improve the functioning range of motion of muscles and tendons include freeing of the muscles and tendons from scar "muscle slide"

procedures muscle and tendon lengthening and tendon transplantation Where nerve deficit persists neurolysis or repair of nerves embedded in dense scar is beneficial. The operations on bone are designed to provide the most favorable structural basis for the action of those muscles shown to have a useful degree of contractibility Resection of carpal bones arthrodesis removal of epiphyses and osteotomy are among the operations used. Capsulotomy may improve neglected joints The results of each operation must be fully developed before another is undertaken

The reconstructive problem is a challenge to surgical ingenuity Essential hand functions such as the ability to pinch and grasp take precedence over less important ones Throughout a course of management which may last for years it is imperative to have the full confidence and co-operation of the patient and to continue physiotherapy and exercises At best the results are often imperfect.

Finally Seddon has described the repair of ischemic nerve lesions and excision of the muscle infarct 3–6 months after onset in patients who have a respectable amount of functional muscle The removal of the binding necrotic mass permits greater benefit to be gained from reconstructive procedures The principle is a good one and deserves further clinical trial and definition.

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42  Treatment of Burns

BURNS ARE a common injury of modern civilization Minor ones are no problem but the care of the severely burned patient is one of the most demanding and professionally arduous tasks confronting the sur geon By the exercise of judgment and technical skill, the time from injury to healing may be materially shortened the debility and disability curtailed and the psychological burden for both patient and surgeon lessened

The injured may appear singly or in numbers as casualties of conflagration or explosion Any physician may suddenly be faced with the problems of the immediate care All must be aware therefore of the need for that promptness of therapy so essential to the survival of the severely burned. To succeed in the management of the injured the surgeon must not only understand the urgency of the fluid therapy but also gain mastery over the threatening complications Often the burns are the only injury Sometimes they accompany other forms of trauma such as fractures or internal injuries from flying fragments The plans of therapy for each injury must be co-ordinated

Thermal burns are the most common The increasing use of petroleum in household heating and as fuel for combustion engines has made this fuel the number one cause of burns Boiling water from the kitchen stove flames from a bonfire or fireplace and the steam and chemicals of industry continue to be hazards High voltage electricity is an occasional cause of severe penetrating burns as well as of electric shock.

From historic time the attention of the medicine man and the doctor has been riveted on "the wound" the obvious lesion and almost every kind of treatment has been recommended It was not until the theater fire in New Haven Connecticut in 1923 that the physiological consequence of the wound received its first modern appraisal Underhill studied the dehydration of the victims measuring the fluid and electrolyte needs Since that time there has gradually developed an understanding of the local and metabolic consequences of the burn trauma and a therapy has evolved to meet them Dehydration must be com batted in order to prevent shock and organ failure The wound must be cared for to prevent infection The possibility of pul monary damage from the inhalation of irritating gases is to be allowed for The resources of the body must be supplemented to prevent anemia and malnutrition. Sur gical care often including grafting of wide areas must be envisaged at the beginning and carried out in stages For success the physician must be alert to all these aspects. Each as ect is considered separately in this

chapter but in practice all must be carried out in an integrated program which starts immediately after injury and runs until all wounds are healed and the patient is re habilitated

Since thermal burns are the most com mon the following account deals primarily with the nature of the injury produced by heat. Injuries due to chemicals may take place more slowly but they have the same general consequences The significant dif ferences in injuries due to electricity will be mentioned at the end of the appropriate section

BASIC CONSIDERATIONS

THE WOUND

Heat damages cells If the heat is mod erate and the exposure of short duration the burn is superficial Only the epidermis or outer layers of the skin are killed and the cells of these layers slough off with a peeling much like that following a severe sunburn Beneath the superficial burn there is a capillary dilatation and increased blood flow which is gone usually within 48 hours This is a so-called "first-degree burn " The swelling of the skin and under lying subcutaneous tissue is slight or only moderate The edema is resorbed within 1–3 days

If the heat is more intense or more pro- longed the damage penetrates into the corium The capillary dilatation and edema are correspondingly more intense and the epidermis is lifted off as a bleb This is a "second-degree burn " and the damage re- quires more time to be repaired than in the case of the first-degree burn. If the bleb roof is left intact, the fluid is gradually re sorbed and the surface under the bleb roof heals over with the regeneration of epi thelium from the hair follicles and the gland crypts After 10–15 days the bleb roof separates and is cast off exposing a tender delicately healed-over surface

If the heat is still more intense or the exposure even more prolonged the entire skin may be killed The blood vessels of the skin itself are destroyed, and the dilated capillaries with increased blood flow in this case are those beneath the skin The dead skin may be charred or may become thickly edematous Usually there are no blebs but cracks appear through which bacteria pen- etrate into the recesses of the wound All epithelial remnants in the gland crypts have been killed and as the skin sloughs away granulation tissue from the under lying fibrous tissue reveals itself The heal ing of this wound can occur only from an ingrowth of epithelium from the periphery or by grafting The ingrowth takes time and if the wound is extensive the granula tion tissue lies exposed until grafted. All such wounds sooner or later become in- fected These wounds are called "third degree burns "

Proper planning of therapy demands prompt recognition of the nature and depth of the burn wound It is frequently difficult to judge the depth immediately after the injury and it is important therefore to take into account the source of the heat. Flash burns of low intensity may give rise only to a superficial burn and light cloth ing may be protective More intense flashes may penetrate clothing A steam burn may be superficial but if the steam saturates the clothing with hot water the burn be- comes deep from the more prolonged con tact If flames reach the skin the burn is usually deep Thus when clothing is ig nited and burns for any time before it is extinguished or pulled off the injury will be deep

The appearance of the skin is the best guide to the depth The first-degree burn is bright pink the dilated arterioles blanch with pressure proving that circulation is intact Deep vessels of the skin are also in tact in the second-degree burn As edema develops second-degree burns begin bleb- bing This should be watched for since it is diagnostic of the depth The momentary arterial constriction taking place immedi ately after injury may at first give the im pression of a deeper burn The subsequent flush as the arterioles dilate tells the true picture

The third-degree burn is lifeless The

third-degree burn from hot water is white and doughy from flames charred Sometimes the hemoglobin of the red cells is fixed in situ and at first glance gives the appearance of an active circulation Pressure shows that the pigment cannot be displaced and this differentiates the wound from the first and second-degree burns Sensation is lost, and a pin-prick test is useful.

Infection

Infection is a common, but most unfortunate complication of the burn wound It can be avoided in many superficial burns by thought and protection but some infection is almost inevitable in deep burns unless the wound is immediately excised and grafted

In its least form infection delays the healing of the wound In a more severe form it may destroy epithelial remnants thus increasing the depth of the wound Rampant in widespread wounds it may be lethal in spite of modern chemotherapy

The normal skin provides an excellent protective barrier against the entrance of bacteria When damaged by heat, the protective barrier may be broken. If the burn is no more than superficial even though blebbed the intact dead epidermis of the bleb roof provides a continued barrier to organisms Once the epidermis is broken bacteria promptly find their way into the wound Multiplication of bacteria with development of infection turns the wound from a burn inflammation into an infectious inflammation The character of this inflammation and its consequences depend to considerable extent on the number and nature of the bacteria

The bacterial infestation depends in part on the area of the body burned and in part *on contamination. The normal skin of the* body harbors bacteria on its surface and to some extent in the gland crypts and hair follicles The staphylococci are so generally distributed that they have to be recognized as normal inhabitants of the skin The organisms of the colon are to be found normally around the anal canal—that is *the anus the perineum the buttocks*, and the thighs The body also provides a positive defense The excretions of some skin areas are slowly bactericidal to certain organisms The beta hemolytic streptococcus for example is killed off by the skin of the hands.

The predominant organisms infecting the burn wound are the staphylococci This is undoubtedly due to their generalized presence on the normal skin. If the surface is broken scarcely a burn wound exists that is not so contaminated and infected Staphylococci are destructive bacteria. Although they may be controlled by protection and antibiotics they are rarely if ever wholly eliminated It should be possible to eliminate the beta hemolytic streptococcus however since it is one of the few organisms that does not become resistant to penicillin It can also be excluded by proper prevention The colon bacteria and organisms such as Bacillus pyocyaneus and B proteus which are normally saprophytic frequently give trouble when deposited as contaminants and are responsible for much of the inflammatory reaction and retardation of wound healing All of these organisms impede the taking of grafts

Infection has now superseded dehydration or shock as the most significant cause of death in the burned patient. Expert management of the fluid-balance problem of the extensively burned patient may succeed in carrying the patient through the initial days after injury only to have the patient succumb to virulent infection in the widespread surface wounds

Pain

The thermal burn is accompanied by *immediate sharp severe pain. Pain persists* intensely in first and second-degree burns for many minutes and gradually diminishes after the first hour or two A deep burn may kill the nerve endings or the pain may be limited to the periphery of the wound where the wound is shallow

Loss of pain and sensation in an area sus pected of being deeply burned is good evi dence of complete skin destruction

The pain of even a moderate burn may be sufficient to cause fainting or acute cir culatory collapse Such collapse is usually promptly and effectively treated by laying the patient prone

Everybody knows that the pain of a burn is soothed by cooling it A child quickly learns to wet the burned finger and blow on it. Cold water therefore is a soothing treatment for the burned hand of a child or an adult Covering a burn with almost any ointment and a dressing is also com forting. Splinting with a firm bandage is helpful in reducing the pain of a burned hand and arm Above all the burned hand should be elevated Resting a burned hand or arm on the back of a chair where it is elevated above the shoulder helps enor mously If the hand hangs down it stings for hours Elevation apparently reduces the tissue pressure and the distention of the damaged tissues

A burn is often frightening The prompt relief of pain is good psychological ther apy Morphine should be used sparingly until damage to the respiratory tract has been excluded (See p 816 regarding pul monary damage) Morphine or other opi ates are seldom needed in the initial hours and should be reserved for later phases Barbiturates are better for continued anx iety

Consequences of Damage to the Circulation

The heat of the burn injures the blood vessels and the blood cells within them The consequences of these injuries may be calamitous if not promptly dealt with Even mild heat increases the permeability of the capillary wall The heat partly by di rect action and partly by reflex action dilates the arterioles increasing blood flow to the damaged part The capillary pres sure is increased and a protein rich fluid seeps out into the tissue spaces In the first-degree burn the capillaries continue to function In the deeper burn the more su perficial capillaries are so damaged that they become plugged with red cells and circulation in them ceases The deeper capillaries damaged as in the first-degree burn continue to function however and the fluid exudes creating the wound edema

Only part of the plasma protein exudes from those capillaries which continue to function The protein concentration of the exuding fluid is a little more than half that of the circulating plasma This concentra tion has been determined by measuring the lymph flowing from burned areas in the dog and the bleb fluid aspirated from burns in the human being In the burn soon after the injury the protein concentration is ap- proximately 4 5 Gm per 100 cc while that of the plasma is 6 5 Gm

The protein concentration of the resid ual circulating plasma is increased because that portion of the protein which does not escape into the tissue continues to circu late in the plasma. The increased protein concentration means a higher than nor mal colloid osmotic pressure This residual plasma circulating in the unburned tissues and organs is therefore able to suck more fluid than normal from the unburned areas and this is the reason for the rapid dehydration occurring in the severely burned patient. Only as fluid is withdrawn from the unburned tissue and therapy is given is the plasma volume reconstituted and the plasma protein diluted Since the red cells continue to circulate the seepage of plasma fluid into the burn wound is ac companied by a decrease in plasma volume and a rise in the hematocrit. The higher the hematocrit the more viscous the blood

The volume of fluid lost from the plasma is proportionate to the surface area of the burn. The more extensive the burn there- fore the more rapid the loss of plasma volume the rise in hematocrit the failure of the circulation and the dehydration of the unburned organs

The red blood cells circulating in the skin and subcutaneous tissues at the time of injury may be hemolyzed by the heat

In a superficial burn the volume of cells so destroyed is small If the burn is deep and extensive as much as 15 per cent of the red-cell mass may be destroyed In areas where the circulation remains intact, hemoglobin is washed back into the circula tion In an extensively burned patient, enough hemoglobin may be resorbed to color the blood plasma pink. The hemoglobin is excreted by the kidney at the earliest opportunity and the initial urine therefore may be highly colored—nearly black in the severely burned Hemolysis is common in a high voltage electrical burn which penetrates deeply into muscle There are relatively many red blood cells in muscle

General Consequences of Failing Circulation

The rapid decrease in plasma volume and somewhat diminished red-cell mass lead to a failing circulation and early or gan damage The first organ to suffer obvi ous changes is the kidney Renal function ceases almost immediately in the exten sively burned person apparently from in adequate renal blood flow If there is much hemolysis the kidney tubules become plugged with hemoglobin Fluid therapy must be prompt and generous to prevent renal damage the so-called "lower nephron nephrosis"

The liver is probably also damaged although this is less well documented The adrenal glands have been found infarcted at postmortem examinations in some pa tients who died soon after an extensive burn It is believed that in burn shock as in traumatic shock from hemorrhage the brain is protected by the sacrificing of other organs first

Edema Formation and the Continuing Need for Therapy

With fluid replacement therapy there is a continuation of the loss of fluid into the burned area and a continuing need for the therapy This continuation distinguishes the burn wound from other traumatic wounds The tearing wound of a fracture or a laceration is promptly sealed off by hemorrhage and coagulation. This is not so of the burn wound in which the edema remains fluid often for many days Plasma continues to seep into the wound and the edema spreads into the adjacent unburned areas. Here the edema fluid is picked up by the lymphatics but the lymphatic vessels are soon overloaded and the edema fluid puddles A burn limited to the hand may be followed not only by edema of the hand but also by edema that spreads slowly up the arm to the axilla and shoulder A patient with a burn limited to both hands and face may develop massive edema of arms shoulders chest abdomen, and even scrotum

The edema develops at a predictable rate in a parabolic curve It is most rapid at the beginning and tapers off and reaches its maximum at approximately the thirty sixth hour The rate is influenced by ther apy The infusion of a noncolloid solution increases precipitously the rate of forma tion.

The cessation of edema formation indi cates that a balance has been reached between the seepage from the capillaries and the resorption of the edema fluid back into the circulation As the capillaries heal resorption gains on formation and edema subsides Edema resorption may be rapid in an uninfected wound after the forty eighth hour—indeed almost as rapid as its formation The rapid resorption of edema indicates that the damage to the capillaries through which circulation still passes is healed with a return of the per meability to normal The relatively rapid recovery of the damaged circulation deep in the wound contrasts with the slower healing over of the wound surface. Capillary healing however governs the dura tion of fluid therapy for the prevention of shock

The fluid nature of the burn wound also means that substances even those nor

mally nondiffusible through the capillary membranes pass freely through the burned wound Antibiotics injected into the sys temic circulation promptly permeate the wound in concentrations equal to that in the plasma Substances applied to the wound surface may also be rapidly absorbed into the circulation through the lymphatics Spontaneous coagulation of the burn wound is slow and irregular The contents of blebs may remain fluid for many days When the burn wounds are infected however coagulation may be rapid

Metabolic Response

A burn unleashes a metabolic and en docrine response typical of injury in general (The pattern is described in Chapter 3) There are special features to the pattern following a burn which lead to important factors in the management of the burned patient. An extensive burn is accompanied by an abrupt rise in meta bolic rate to high levels The widespread surface of the wound is probably responsible The metabolic rate subsides only as the wound heals The increased nutritional needs end up in rapid body wasting unless special thought is given to the feeding of the patient

TREATMENT

The care of the burned patient involves the management of the wound from the first protective dressing to the final heal ing the fluid therapy in anticipation of shock the control of infection the main tenance of good nutrition and help with the psychological adjustment to injury In many ways each of these aspects is inter related and attention to all should be car ried on simultaneously the emphasis de pending on the exigencies of the moment

The Wound

Superficial burns do well under various forms of treatment. The deep burn is the challenge however and here judgment counts In all of the alternative methods efforts are bent to obtaining the earliest possible healing

The first-degree burn needs no covering although the patient is more comfortable if the burn is smeared with grease or other ointment The intact epidermis prevents the penetration of organisms

The second-degree burn demands local treatment There are two general approaches the so-called "closed method" employing a dressing and the "open method" Both of these in general terms are equally effective The closed method aims to eliminate contamination by keeping the bleb intact and by straining out organisms in the dressing The open approach employs the protein coagulum which forms over the surface as the barrier against bacteria. Whichever approach is used every effort should be made to pre vent bacterial contamination. In the closed method this is done by protecting the blebs so that they do not rupture Bulky dressings should be used The dressings prevent the intrusion of bacteria should the blebs rupture beneath A bland oint ment such as petrolatum is to be used beneath the dressing Vital dyes and other necrosing substances are best avoided since if they reach the tender epithelium beneath the blebs they may only add to the destruction In a burn of critical depth chemical destruction on the surface may turn the wound from a partial to a com plete-thickness injury

If the open method is employed the burn should be exposed in a protected at mosphere Patients should not be crowded The filtered air of an air-conditioned room is to be preferred to one in which the wind blows in dust All personnel should be masked and every precaution such as oil mopping of the floors is to be taken in order to diminish the number of contami nating bacteria reaching the wound sur faces

In burns of full thickness there are again, two alternatives (1) immediate

excision and grafting and (2) spontaneous dissolution of slough with delayed grafting The immediate excision followed by immediate or prompt grafting is the method preferred for every full thickness burn of undoubted destruction and of limited extent. By this approach the wound is debrided of all necrotic tissue and closed by the graft bacterial invasion is shut out. The most successful takes of grafts and the most prompt healing are obtained by this method It may be unwise to employ this approach however in patients in whom physiological balance is precarious and in whom the extent of the burn injury limits the donor sites available for grafting The impediments to this approach are therefore doubt in regard to the depth of injury precarious physiological control, undesirability of an extensive operation so soon after injury and lack of available donor sites

The spontaneous dissolution of the slough and delayed grafting will be found advisable in the more extensively burned patients No set rule can be made when this approach is to be used Its indications are the reverse of the immediate excision and grafting Every measure is taken to cut down on the unnecessary bacterial contamination by strict aseptic precautions The initial program may be carried out by either the closed or the open methods described above for second-degree burns Whichever method is employed experience has shown that eventually the unhealed wounds will be cared for best by the closed method until ready for grafting This is because sooner or later all of the deep unhealed wounds become infected

Every effort is taken to remove slough as soon as it is loosened This is accomplished by frequent changes of dressing with meticulous care to excise all available pieces of dead skin and subcutaneous tissue As soon as compact red granulations appear on the surface of the wound and all slough has been removed the grafting should be carried out Only as the wound is closed by grafts will the infectious process subside

Infection

Prevention of infection is the first rule in the care of the wound This is accomplished by protecting the wound against bacterial contamination Since bacteria, particularly staphylococci, are always in the periphery of the burn wound some contamination is inevitable with change of dressings To keep the infectious process at a minimum chemotherapy is therefore a part of burn therapy Such chemotherapy should be both local to the wound and systemic Choices in chemotherapy are available and a variety of agents should probably be used Frequent cultures of the various wounds are helpful in identifying the organisms and indicating the agents best suited

Penicillin is useful because it virtually eliminates the beta hemolytic streptococcus one of the most destructive organisms This organism is unable to develop resistance to penicillin Penicillin is also the least toxic of the antibiotics and may be used in large doses

Staphylococci develop resistance to penicillin if they are not resistant to begin with It is often advisable therefore to add another drug for control of the staphylococci. Most of the broad spectrum antibiotics are effective against staphylococci and are also useful against the gram negative organisms As resistance is developed by the various bacteria to the agent in use it is often advisable to change to another antibiotic

Antibiotics are also wisely employed locally Penicillin and Aureomycin® are available in ointments It is best not to apply the sulphonamides locally to a wound They are rapidly absorbed and if the wounds are extensive a toxic level may be reached in the blood with renal shutdown In the same manner other antibiotics with a toxic level such as streptomycin are not to be used locally on the wound The dosage of penicillin which may be absorbed has no ceiling

Meticulous care during the change of dressings particularly in regard to elimi

nating additional contamination is helpful in controlling infection Immobilization by splinting is to be used for wounds of extremities

Shock

Primary shock, or vasomotor collapse has already been alluded to It is best treated by laying the patient prone and reassuring him Primary shock is rarely life endangering unless due to an electric current and cardiac standstill The anxiety of the patient may be helped by a barbiturate If the pain is prolonged morphine is useful, but it should be used with restraint unless pulmonary injury has been excluded

Secondary shock due to the loss of plasma must be treated promptly and generously The aim of therapy is to replace that which has been lost from the circulation and to anticipate that which will be lost in the hours to come In this manner the circulation to the unburned organs and tissues will be maintained it is upon these structures and not the wound that life depends.

There are a variety of formulas which may be used to guide the fluid therapy First, there are the surface area formulas These stem from the principle that the volume of plasma fluid lost from the circulation is proportional to the area of surface burned.

1 The simplest of these formulas the *basic* surface-area formula is as follows For each per cent of surface area burned in an average-sized adult 150 cc. of fluid will be needed in the first 24 hours One half the amount is to be given in the first 8 hours when the rate of plasma loss is fastest and the second half in the subsequent 16 hours One half the amount is given in the second 24 hours In each 24-hour period 2 000 cc of additional fluid is given for renal function and insensible water loss

Regarding the nature of the fluid to be given again the aim is to return to the circulation what has been sapped from it and in addition to give the normal fluid need of the kidney Since a dilute plasma is lost a dilute plasma is returned Half plasma half saline solution is more dilute than ideal but is convenient to remember Since the protein concentration of bank plasma is already diluted by the citrate and glucose solutions added to preserve it the ideal is more nearly approached by 125 cc of plasma and 25 cc of saline solution for each per cent burned

Water or solutions less concentrated than saline are most suitable for the renal function moiety These are best given by mouth if the gastrointestinal tract is functioning Fruit juices ginger ale milk and other pleasing fluids may be used If the patient is vomiting the moiety is given intravenously as glucose in water

2 The foregoing formula provides too much for children and so a formula incorporating the square meter of body surface has thus been devised For each per cent of a child s surface burned 85 cc. of the plasma mixture is given for each square meter of body surface To estimate the surface area of a child or an infant, it should be recalled that the average 2 year-old infant has a body surface of 0 5 square meter a 9-year-old child, 1 square meter and an adult 1 78 square meters The kidney moiety is also modified the infant receiving from 1,200 to 1 500 cc per square meter irrespective of the per cent of the body surface burned In children with respiratory tract damage the lower figure is considered preferable

3 The weight modification of the above adult formula as advocated by Evans may also be used It gives 75 cc of plasma and 75 cc of water for each per cent burned for each kilogram of body weight A volume identical with the basic surface area formula is given therefore to a patient weighing 75 kg A drawback to the weight formula is that it tends to prescribe too little for the child and too much for the stockily built or fat adult

4 There is also the interstitial-space expansion formula suggested by Moore This is based on the anticipated expansion

of the extracellular space as a result of wound edema One amount is applied to all patients with burns covering 30 per cent of the body surface or more The following amounts are given during the first 48 hours (*a*) for wound edema a volume equal to 10 per cent of the body weight and (*b*) for external loss an amount varying according to the area of the wound—1 000 cc for burns of 25–30 per cent 2 000 cc for those of 35–60 per cent and 3 000 cc for greater burns The quarters of the total volume are distributed much as in the basic surface area formula—two quarters in the initial 12 hours one quarter in the subsequent 12 hours and the fourth in the second 24 hours This formula has the advantage of simplicity

Whichever formula is chosen the plan is to be modified according to its success Renal output is the most readily available and probably the most accurate guide to the adequacy of the fluid therapy Each patient should have an indwelling catheter placed in the bladder immediately after entry to the hospital The volume and specific gravity should be measured hourly The volume should be maintained between 30 and 60 cc If the volume is less cessation of renal blood flow may be impending If greater a plethora may develop with pulmonary edema and congestive heart failure Similarly the specific gravity should be neither high nor low These are simple determinations which can be carried out by the nurse The appropriate change in rate of fluid administration can be immediately recognized at the bedside and made without waiting for a laboratory determination It is also wise to check the patient s progress with periodic hematocrits and hemoglobins

With these formulas red-cell loss from the burn is to be replaced by whole-blood transfusion The presence of hemolysis in the plasma and hemoglobin in the initial urine warns of the need for red cells Ten per cent of the estimated red-cell mass may be considered the maximum destroyed and the needed replacement in the first 36 hours

If plasma and whole blood are not available then a plasma substitute or so-called "expander " may be used The colloid property of the substitute exerts a colloid osmotic pressure comparable to that of the plasma proteins The substitute is dissolved and approximately diluted with plasma-electrolyte equivalents If in an emergency neither plasma nor substitute are available glucose in saline solutions may be used. If in a catastrophe no intravenous solutions are accessible water and salt-containing solutions are to be given by mouth to the limit of the capacity of the gastrointestinal tract.

5 Another type of formula is the whole-blood and saline program of Moyer It overshoots the need for red cells providing a blood with a higher-than normal hematocrit If the burn is of the type leading rapidly to anemia then this program of therapy has the advantage of anticipating the later need for transfusion

Pulmonary damage from inhalation of irritating gases frequently poses a special problem When a fire occurs within an enclosed space the casualty burned within that space may have inhaled a toxic gas. Such a gas is a product of combustion Capillary permeability of the lung tissue may be increased by the gas with resulting pulmonary edema This edema is not to be confused with that of overhydration. The presence of lung damage demands restraint in the fluid therapy of the burned patient The possibility of this pulmonary damage is always to be considered in any patient burned in an enclosed space If damage is present the fluid therapy must be restrained in order not to augment the pulmonary edema

Restraint in fluid therapy is to be exercised after the thirty-sixth hour It is at approximately this hour that maximum edema is reached and reduction of edema begins The fluid resorbed supplants that previously needed by vein The renal output is to be watched closely for this change in need With a rise in urine volume the fluid therapy is curtailled. Often after the forty-eighth hour no more than a normal person s daily fluid intake is required

ANEMIA

Anemia frequently develops rapidly in patients with extensive full thickness burn wounds The early source of hemolysis and the need for replacement have already been alluded to It is the continued loss of red-cell mass which is of utmost impor tance The source of this red-cell loss is not as yet understood It is presumably related to infection since it is associated with infected wounds and is not apparent until after the forty-eighth hour As much as 600 cc. of whole blood daily has been required to maintain the red-cell mass in the first 10 days after injury Neglect of this anemia encourages infection and mal nutrition. There may also be a later phase in the third and fourth weeks when com parable amounts of whole blood are needed. This need is apart from the loss of red cells at the grafting operations

MALNUTRITION

Malnutrition like anemia may develop rapidly in the severely burned patient The wasting is in part a response to the trauma, but since it is quantitatively greater in the burned patient than in those suffering other forms of trauma it is probably in large part related to the elevated metabolic rate which accompanies an ex tensive burn. It is also hastened by the complicating infection. In addition to the rise in oxygen consumption there are in creases in nitrogen excretion and probably in the rate of utilization of vitamin C and other specific food substances A protein deficiency and loss of appetite are com mon. Every effort should be made to provide food and if necessary supplementary intravenous therapy Whole-blood transfu sions are useful in this regard also

ENDOCRINE THERAPY

There is no proved specific endocrine therapy for the burned patient who was normal prior to burning The patient with an antecedent endocrine deficiency—such as Addison s disease myxedema or hypopituitarism—is an exception In these diseases the adrenal cortex may not be able to respond adequately to the acute demand occasioned by the trauma Cortisone ther apy may be needed In contrast the diabetes mellitus patient who has been main tained adequately on insulin has adrenal glands able to respond in normal fashion

There is no doubt that an increased se cretion of adrenal corticoids is a part of the normal response to trauma. This has been dealt with in greater detail in Chapter 3 on the Metabolic Response to Trauma In summary the best type of endocrine therapy is the maintenance of a normal blood flow and nutritional supply to the various endocrine organs including the adrenal pituitary and thyroid glands and the pancreas Inadequate replacement of the blood volume may lead to organ dam age and inadequate endocrine support

PSYCHOLOGICAL ASPECTS OF THERAPY

A burn accident frequently poses special psychological problems including fear of death dread of disablement and depend ency dread of disfigurement and some times guilt and grief Unless the doctor and nurse are aware of these problems and prompt in helping the patient with them the patient may become increasingly diffi cult to manage and care for Dressings and operations also pose a hazard The patient may refuse to eat. Adults and children may regress to infantile patterns of behavior in face of the anxieties Thus each source of psychological problem must be sought and dealt with Only in this way can the course be smooth for the patient the doctor and the nurse

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43  Injuries Due to Cold

EXPOSURE TO cold produces several differ ent types of injury which can be roughly divided into two major groups The first group is caused by cold without actual freezing of the tissues and includes the conditions described as trench foot im mersion foot chilblain and erythrocyanosis The second group of injuries occurs when the tissue is actually frozen, and con sists of the various degrees of frostbite The more serious condition frostbite will be discussed first

FROSTBITE

DEFINITION AND INCIDENCE

Frostbite results when portions of the body are exposed to a sufficiently low tem perature to produce freezing of the skin plus or minus the deeper structures The skin fortunately has the ability to cool below its normal freezing point before actual freezing occurs a phenomenon first de scribed by Sir Thomas Lewis This "super cooling allows the skin to reach tempera tures of −2.2 to −10 C before freezing occurs The skin is most susceptible to freezing when wet and most resistant when unwashed and oily Apparently here is one situation where a thin layer of dirt is not only advantageous but also accept able as the Eskimos have long realized Since sea water freezes at −1 9 C frost bite does not occur from immersion.

Frostbite is seen most frequently in war time and in the recent Korean conflict the American forces suffered 55 331 such casualties Such cold injuries are rare among those who live in cold climates since they have learned how to dress to prevent such injuries

In civilian life the condition is primarily encountered among those who work out doors and who are not from past experi ence aware of the danger It is also preva lent among alcoholics who may fall into a drunken stupor in locations ideal for sus taining frostbite Frostbite will take its toll of improperly clothed people when the temperature falls below 14 F Age does not appear to be an important factor Predisposing factors are a previous history of cold injury hyperhidrosis high vasomotor tone and heavy smoking People in shock or suffering from injuries or from anoxia (high altitude) are likely candidates for frostbite if exposed. Other predisposing conditions are wind with the cold chilli ness of the rest of the body malnutrition fatigue and compelled immobility It is interesting to note that while the radiation surface of the fingers is only 3 or 4 times that of the face the susceptibility of the fingers to cold injury is 50–100 times greater

Clinical Findings

As the part becomes cool a burning stinging pain develops at about 15 C (59 F) and this changes to numbness as the temperature goes down The frozen area looks white and feels firm This situation persists until the part is thawed, when it becomes painful and red In less than 3 hours there is swelling and in 2–24 hours vesicles appear if the injury is of sufficient severity

Orr utilizing the army experience in Korea has described three degrees of frost bite which make a useful classification and describes the course of events

First Degree—Essentially a minor injury followed by edema for 5–10 days and desquamation on the fifth to the thirtieth day

Second Degree—Vesicles occur which are black and hard for about 14 days and peel off in 17–36 days Edema is not marked There is sensitivity to cold later on and increased perspiration for 2–7 weeks

Third Degree—The entire hand or foot is swollen for about 6 days with anesthesia for 1 week and limited motion and burning or stinging for the first few days Pain returns in 5–17 days and lasts 2–5 weeks A hard dark eschar develops (This did not heal without surgery in 15 per cent of the cases) Coldness and hyperhidrosis persist for 4–10 weeks

The duration of exposure and the degree of coldness are the two most significant factors in determining the amount of damage A frostbitten digit or extremity may besides suffering severe skin damage also suffer deeper injury which can go on to fibrosis of the muscles and joint capsules with resulting stiffness

Gangrene when it develops goes through a brief wet period as a rule If the frostbite involves the very deep tissues so that the major blood vessels are destroyed edema and wet gangrene may be absent or minimal with early development of dry necrosis.

Pathology

Following freezing, edema of the tissues is observed with the formation of blisters some of which may contain blood By 24 hours in the significantly damaged tissues there is stagnation or "silting" of the red blood cells in the capillaries Thrombosis is not common and is never seen in the first 24 hours Inflammation is seen especially at the margins of the frozen area with fibrin and white blood cells in the tissues. Degeneration of the muscle fibers and myelin sheaths of the nerves is demonstrable Later if there is to be actual tissue loss necrosis will be seen After 3 months thickening of the intima of the arterioles may be observed also later fibrosis of muscles and other subcutaneous tissues may occur This fibrosis is well demonstrated in Figure 609 on page 825 If the digits are involved, sclerodactylia may be the result, with short, sclerotic finger tips irregular nails and smooth rigid skin

Pathological Physiology

Frostbite damages in two different ways by direct damage to the cells by the cold which may or may not be reversible and by changes in the circulation of the blood and lymph Which form of the injury is the more important is a debated point but obviously both must be considered in studying the problem The circulatory changes continue after the exposure is over and they undoubtedly increase the damage caused by the trauma of freezing

Little is known about the direct effect of freezing on the cell itself It is known that certain cells may freeze and yet survive to function Many cells are destroyed when their temperature falls below −6° C Even if the cells survive undoubtedly many are damaged and are slow to recover It is obvious that the results of freezing are due to more than just the relative anoxia caused by the cessation of blood flow during the frozen state since the results of freezing a part are much more damaging

than even a much longer period of ischemia caused by a tourniquet In the frozen state metabolism is so far reduced that necrosis from oxygen lack is not a factor Tissue damage of serious degree would therefore seem to be as we have noted above a combination of cell damage due to freezing plus changes which take place *after thawing It is of interest also that* hemoglobin will not give up its oxygen at temperatures below 10 C

Much has been learned about the vascular changes. Sir Thomas Lewis described the reaction of skin to cold Primarily defense against cold is vasoconstriction which protects the body as a whole at the expense of the local area This vasoconstriction on exposure to cold is of three types first there is constriction of the superficial vessels from the direct effect of cold on smooth muscle second there is generalized transient reflex vasoconstriction and third there is generalized long lasting vasoconstriction when cool venous blood reaches the central nervous system The latter does not occur if the venous return from the limb is occluded

In an effort to ward off frostbite the skin has a local defense mechanism After initial vasoconstriction a transient intermittent vasodilation occurs which raises the temperature 5 *to 8 C after the initial* cooling. Thereafter there is intermittent vasodilation and constriction governed by a local axon reflex.

With thawing the vasoconstriction is released and vasodilation occurs This is of maximal degree and is caused by the reaction of the vasomotor center to protein breakdown products in the blood by paralysis of the terminal vasoconstrictor nerve fibers and by a direct response to histamine-like substances in the capillary walls After a few hours the flow through the capillaries becomes sluggish however owing partly to the loss of plasma through the injured capillary wall which leaves the blood with a high concentration of red cells These cells tend to clump or "silt" out, obstructing the flow of blood

After thawing there is edema formation and a marked increase in lymph flow The latter has been measured by means of a cannula in a lymphatic trunk of the frozen extremity of the experimental animal and found to be maximal in 1–2 hours The protein concentration of this fluid ranges from 3 3 to 4 3 Gm per 100 cc This re*action is identical to that after a burn as* observed by Field Drinker and White

That the edema may be due to leakage from damaged capillaries has been shown by use of fluorescein dye Following frost bite an abnormally high concentration is found in the skin Later in 8–14 hours with cessation of capillary blood flow the dye disappears The dye is also found in the blisters unless the situation is very severe when it is not present.

The cause of the edema may also in part be the histamine-like substance described by Sir Thomas Lewis which is produced by trauma and acts to increase capillary permeability Similar but less marked edema may occur when there is exposure to cold which is not sufficient in degree to cause frostbite

During the first few hours blood flow through the frostbitten area is rapid Soon capillary flow falls almost to zero owing to the silting of the red blood cells pre*viously described which creates a mechan*ical block. No thrombosis is seen in the first 24 hours and usually none later although in severe cases it will occur There seems fairly universal agreement that thrombosis plays a small role in the injurious effects of frostbite

Demarcation of the tissues destroyed by frostbite is slow to develop—a fact which should compel the surgeon to be very patient in making his decisions The outer skin and nail may be cast off eventually to reveal surprisingly normal new skin beneath By the sixth day it may be possible to identify the amount of skin that will be lost but in some cases many weeks must go by before it is certain whether a digit is irreversibly damaged or not If the skin temperature falls to the room temperature

and cannot be elevated by a sympathetic block the outlook is not good

Treatment

The aim of treatment obviously is to save as much tissue as possible As a rule unlike the burn problems in frostbite there is not the danger of a fatal outcome Methods are directed at (1) rewarming the solidified area (2) *overcoming the changes* in the blood vessels (i.e the vasospasm and the silting of the red cells) and (3) reducing the edema if that is considered to be harmful. Certain fairly obvious general measures will be noted however before discussing the three specific methods of treatment

If the feet are affected the patient should not walk a single step from the time he is first seen until the healing is well along. Rough cleansing or rubbing the area is obviously too traumatic Antibiotics are extremely important in the more serious cases because infection in a borderline case may make the difference between saving or losing the involved area. The body is kept warm and the injured part, once it has thawed is exposed to room temperature Tobacco is forbidden because of its well-known vasoconstricting tendency The position in bed should be horizontal or with the injured part slightly elevated

Methods of Rewarming —The problem of how best to thaw the frostbitten area has long been of interest The Eskimo who is well acquainted with cold is eager to thaw the part as soon as he can and he does it at body temperature—e g putting the frozen finger in the opposite axilla Perhaps then he can be counted in the group which favors rapid rewarming On the other hand many years ago Baron Larrey Napoleon s surgeon in the Russian Campaign first cautioned against rapid rewarming and called attention to soldiers who came in with frostbite were warmed near stoves and soon lost their legs Since then the debate has gone on

The current proponents of slow warming either in a cool bath or in a cool room say that they find less gangrene in their experimental animals or patients and think that edema is slower to appear and is less marked Cooling boxes have been devised to keep the injured part from rewarming too rapidly A justification for this thesis is the fact that at lower temperatures metabolism is reduced and the demand for oxygen is therefore less hence the argument that in the period of poor capillary circulation *fewer cells will be destroyed* It is generally agreed that the remainder of the body should be warmed and kept warm, to produce vasodilation. This traditional concept of slow rewarming of the injured area has recently come under close scrutiny and there is much evidence that rubbing with snow or an otherwise slow warm up is not good Experiments with rats mice rabbits and dogs demonstrate less damage when the frozen part is rapidly rewarmed at about 40 C for short periods and then left at room temperature. Edema comes earlier than in the controls but is not more severe In another experiment, human beings who were to have amputation of an extremity had comparable areas on this extremity frozen then rewarmed slowly or rapidly The rapidly rewarmed area appeared to fare better

It would seem that rewarming at about 40 C for approximately 10 minutes is the best method in the light of current experimental evidence Once thawing has occurred further warming is not only harmful but probably deleterious Usually the doctor first meets the frostbitten patient after the frozen area is thawed, and so he has no decisions to make as to which method to use

Vasodilating Measures —When thawing has come about the question arises as to what can further be done to prevent tissue loss or injury While there has been little to suggest vasospasm in most cases in the early postfreezing period investigators naturally enough were interested in the effects of removing or blocking sympathetic activity Sympathectomies were carried out on experimental dogs prior to freezing without apparent benefit as meas

ured by the amount of tissue destruction Others have found but slight benefit from such procedures *Currently the evidence* does not indicate that sympathectomy or sympathetic blocks in the early treatment of frostbite will be very helpful * Weeks or months after injury if ulcers are slow to heal or vasomotor hyperactivity can be demonstrated or if major pulses have disappeared sympathectomy may be very valuable

Sympathetic block with tetraethylammonium chloride did not seem to alter the course in frostbitten rabbits according to one group of observers whereas another group thought it helped a little The results in human beings will be hard to evaluate If the drug is useful it will certainly not have a very dramatic effect Another agent is Hydergine® a combination of three derivatives of ergot—dihydroergocornine dihydroergocristine and dihydroergokryptine Experiments have shown that rats with frozen tails and feet incurred under conditions of pressure similar to *high-altitude* exposure to extreme cold suffered less tissue loss when given this preparation, which is a vasodilator Evaluation in human beings has not been completed

Anticoagulant Therapy —As already discussed there is little evidence that the major changes which follow frostbite are due to any appreciable extent, to thrombosis. It is true that in severe cases thromboses have occasionally been found Usually it is the clumping or silting of the red blood cells which produces the circulatory insufficiency if any exists It is reasonable however to evaluate the effect of heparin and this has been done The results are good in the hands of some investigators and poor in the hands of others After reviewing this aspect of the problem it would seem that in severe cases heparin should be given a trial In cases where thrombosis is not present it is hard to see why heparin would help since it does not *prevent the silting of the red cells*

Other Medications —Adrenocorticotropic hormone (ACTH) cortisone alcohol amylnitrite aspirin and nitroglycerine have been evaluated on the experimental animal and evidence of clear-cut benefit is lacking Slight benefit is claimed for rutin which is thought to prevent capillary leakage and stasis and for Benadryl® which opposes the histamine-like substance

Pressure Dressings —Plaster casings or other means of limiting edema have been investigated and thought useful by one group and useless by another In view of the difficulty of applying pressure without trauma and the disputed experimental results use of this method seems contraindicated at present.

Late Treatment —It has long been appreciated and cannot be overemphasized that the doctor must be in no hurry to judge how extensive an amputation must be done Many times the doctor will despair of preserving toes only to have a casing on the toe fall off revealing quite healthy skin and structures beneath it So before operating the disease must be allowed to run its course until the extent of destruction is certain When an amputation is necessary it is performed very close to the junction of normal and dead tissue The usual rules of amputations for lesions due to vascular insufficiency have no application to these problems Also it is late in the course of therapy that consideration must be given to sympathectomy If ulcers do not heal if major pulses are absent or if signs of sympathetic overactivity are present sympathectomy may be of great value Hyperhidrosis may be sufficiently marked to make this operation worth while

Exposure to cold of sufficient degree to freeze tissue produces vasoconstriction during the period of freezing followed by initial vasodilatation on thawing Later the capillary circulation is markedly impaired by concentrations of red cells in the capillaries (silting) Also after thawing there

* It was demonstrated at the Royal Naval Hospital in Halifax in 1943 that neither sympathetic block nor spinal anesthesia caused any further increase in temperature *of the lower extremities in* cases of immersion foot after the initial thawing and spontaneous vasodilatation that naturally occurs.

is edema due to leakage of plasma from the capillaries This is similar in many ways to the conditions following burns Skin muscles blood vessels nerves—all structures can be injured by the frostbite

Evaluation of the many suggested methods of treatment is difficult. At present the most reasonable approach appears to be (*a*) rapid thawing (40 C for 10 minutes) (*b*) bed rest with the injured area exposed or protected by a light sterile dressing (*c*) no smoking (*d*) body warm (*e*) heparin if lesion threatens one or more digits (*f*) appropriate medication for pain (*g*) antibiotics and (*h*) patient observation by the surgeon When tissue appears obviously dead debridement should be carried out If after weeks or months major pulses are absent or if signs of excess vasomotor activity and sweating are present, or ulcers slow to heal sympathectomy is indicated Amputation should be performed only after long observation and at a level immediately adjacent to the necrotic area By these methods tissue loss and late disability should be kept at a minimum

The Korean conflict produced many patients with cold injury In Orr s report 43 6 per cent of these patients had full thickness skin injuries Only 15 per cent of the group required surgery however showing the value of conservative treatment. It is important therefore not to be overly concerned by the initial terrifying appearance of the damaged area

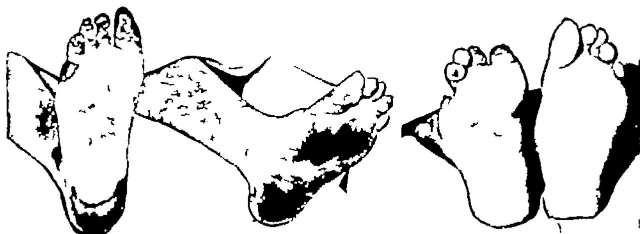


Fig 608—**Left** gangrene in case of trench foot **Right** results of conservative treatment (From White J C and Scoville W B: Trench foot and immersion foot New England, J Med. 232 415 1945 The photographs were taken of a patient of R. H. Patterson and F M Anderson at Letterman General Hospital.)

OTHER COLD INJURIES

Exposure to cold which is not sufficiently severe to cause freezing of the tissues can nevertheless produce injury of significant degree There are several syndromes, which will be discussed in the following pages

Trench Foot and Immersion Foot

Trench foot and immersion foot are forms of thermal injury resulting from prolonged exposures to temperatures which are not low enough to produce freezing but which can produce tissue damage Usually but not necessarily the extremity is wet thereby increasing the loss of heat Another predisposing factor is a period of dependent immobility with resulting stasis of the circulation frequently accompanied by some constriction of the extremity by boots or by a person s being forced to remain for long periods with little chance to shift position as in a small foxhole or a cramped lifeboat In both the Army and Navy attempts have been made to reduce the inci

dence of this incapacitating injury by instructions to personnel for avoiding the foregoing factors

As the condition develops the foot becomes cold and numb and feels like wood to the victim There is relatively little pain On removing the boots and warming the extremity pain swelling and paresthesias develop If the injury is severe enough blisters blebs and even hemorrhagic bullae may develop Superficial gangrene of the skin may occur but usually the deeper layers of epidermis survive to permit spontaneous healing. The injury may however progress and necessitate amputation. Figure 608 shows the extent of damage that may occur

Later such feet become tender and remain painful, owing to the tissue destruction and fibrosis Hyperhidrosis is a frequent finding for a few months and unusual sensitivity to cold may persist for years

Pathological Physiology —The injury is similar to frostbite with vasoconstriction while cold followed by a period of vasodilatation and edema due to capillary injury The later symptoms of pain tenderness hyperhidrosis and stiffness are due to damage to the vessels nerves muscles joint capsules and subcutaneous tissue From the observations of trench foot by Edwards and immersion foot by White and Warren (Fig 609) it seems obvious that much of the late pain and persistent rigidity of the involved extremities is due to the contraction of scar tissue



Fig. 609 —Photomicrographs of biopsy sections in the terminal healed phase of immersion foot. Left biopsy of extensor brevis digitorum muscle showing fibrous tissue around nerves (reduced from × 50 phosphotungstic acid–hematoxylin stain) Right biopsy of extensor brevis digitorum muscle showing perineural fibrous tissue and edema of nerves (reduced from × 300 Masson *trichrome stain*) (From White J C and Warren S *Causes of pain in feet after* prolonged immersion in cold water War Med 5 6 1944)

Treatment —*There seems to be agreement that exposure of the feet to room temperature and rest with slight elevation*

are indicated. Prevention of infection is important and is carried out by keeping the injured area well protected from contamination and by use of antibiotics As soon as pain subsides Buerger exercises and whirlpool baths are instituted to aid in mobilizing the patient.

Edwards found that the average patient could walk in 24 days and that the average hospital stay was 60 days Most soldiers returned to full duty On the other hand many of the survivors of ships sunk in arctic waters during World War II were incapacitated for further duty at sea Their feet remained too stiff painful and sensitive to cold to permit further prolonged standing on exposed wet decks although amputations even of single digits were rarely necessary

CHILBLAIN

Chilblain, an injury caused by repeated exposure to cold, is characterized by a red swollen itchy area usually overlying the dorsum of the digits The skin may blister or ulcerate and healing is slow to occur Protection from cold is usually the best treatment

ERYTHROCYANOSIS

Erythrocyanosis is a similar condition found over the skin of legs that are chronically exposed to the cold with little protection The skin becomes purple tense and shiny with edema and blisters The changes last until warmer weather This disease is most common among young women

These two local injuries chilblain and erythrocyanosis are obviously very similar to trench foot in that the tissues are damaged by chronic exposure to cold above freezing temperature The changes are slow to disappear and are seen much more commonly in England and Scotland where houses are colder and damper than in the United States These injuries have been well described by Sir Thomas Lewis

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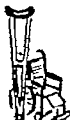
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44  Physical Medicine and Rehabilitation

In this chapter no attempt will be made to describe in detail the use of physical agents or other rehabilitation procedures in the treatment of all the various types of fractures In other chapters pertaining to specific fractures the reader will find the period of immobilization recommended as determined by the stability of fixation. In most instances information is also given concerning the type of exercises that may be employed safely and the time when they may be started. The purpose of this chapter is to present the general principles of the use of physical medicine in the treatment of fractures and of other rehabilitation procedures when indicated in the more complicated problems

Physical medicine plays no role in the reduction or fixation of fractures It is well recognized that fractured bone ends must be held immobile in constant apposition in order to encourage union This immobilization, of course causes some undesirable changes in the soft tissues and adjacent joints. A primary role of physical medicine is to minimize the harmful effects of immobilization Procedures are accordingly selected to aid in the safe absorption of hemorrhage and exudate and to minimize muscular atrophy edema formation joint stiffness and circulatory deficiencies The physical agents most commonly used for this purpose include various forms of applied heat specific types of massage and —most important of all—active exercises sometimes including the use of mechanical apparatus Because of the need for active exercise particularly to regain the skillful use of extremities occupational therapy is frequently an important adjunct. In order to prescribe these physical agents intelligently it is important that the physician or surgeon understand the underlying physics and physiological actions which will be reviewed here

HEAT

A variety of physical agents is available for increasing local tissue temperature The physiological effects of these heating agents are fundamentally the same although there is considerable variation in their efficiency and the ease and comfort of application. Among the known physiological effects of heat is sedative action for the relief of pain Although a slight raising of tissue temperature elevates the pain threshold it seems likely that the most important mechanism of relieving pain is through reduction of muscle spasm if present The primary local response to heat

however is change in circulation An in creased arterial flow is produced resulting in a dilated capillary bed and increased pressure This increased blood supply however is not without an undesirable ef fect, namely increased swelling In most traumatized areas there is some injury to the lymphatic and venous drainage and excessive heating may easily cause in creased swelling and pain with loss of motion For this reason the use of heat alone is deprecated whereas heat may be quite beneficial when followed by proper massage and exercises including attention to positioning during both heat application and later exercises

There are a great many methods for applying heat *In general* those which are most easily applied which may be repeated as often as needed and which are least costly are the most desirable

Conductive Heating

Perhaps the simplest forms of heating are conductive This includes the use of warm water soaks hot packs and heating pads.

Hot water soaks can also be given in the form of the whirlpool bath Here the agita tion of the water is thought to have an ad ditional stimulative effect on the cutaneous circulation and in the relief of muscle spasm together with certain psychological therapeutic actions The whirlpool bath has the disadvantage of dependency of the part emersed. This works against venous return and in the presence of edema may not be so effective as other agents which can be given with the part horizontal or elevated

One of the most effective methods of conductive heating is a hot moist pack known commercially as the Hydrocollator® pack. This consists of a ribbed canvas pack containing a gelatinous chemical which has a high absorptive power for water so that, after the pack is saturated with water and heated it may be held up with only a few drops falling out thus obviating the need of wringing. After the heat is given *off in the form of vapor* the pack remains dry instead of cold and wet The pack is wrapped in five or six thicknesses of turk ish towelling adjusted to comfortable warmth and the towelling reduced as cool ing occurs This pack is suitable for home use It is safe to heat the water to as high as 170 or 180 F or slightly below boil ing The safe temperature of the water baths on the other hand ranges between 104 and 110 F

Another form of conductive heating often of value particularly for the hand is the paraffin bath Proper mixtures of paraf fin wax and oil (usually 7 1) are used so that the melting point is between 125 and 130 F By several repeated emersions a *layer of wax solidifies like a glove* The in jured part may then be either left in the melted paraffin or wrapped in towels for the desired period of time

It has been found that adequate local heating can be obtained in about 30 min utes by the conductive methods described

Radiant Heating

Another relatively simple method of heating utilizes radiant energy which is absorbed by the tissues and converted to heat The energy source is infra red radia tion which may be obtained from the usual tungsten filament light bulbs of suffi cient wattage nonluminous infra red coils or carborundum elements The larger the area to be treated the greater the wattage needed the range being from 250 to 1 500 watts Heat lamps safe for home use are available including lamps with Pyrex bulbs and inside reflective coating and lamps with metallic reflectors properly in-sulated to prevent overheating One neces-sary precaution is that the source of heat be so angled that, in case of breakage of the bulb hot parts will not fall on the skin The heating source is set at a comfortable distance this will vary between 15 and 30 inches on the average depending on the wattage of the bulb or element Adequate rise in temperature can usually be ob-tained by infra red radiation in 30 minutes

Conversive Heating

The conversive method of heating employs the principle of converting high frequency electromagnetic energy into heat in the tissues This is known as "diathermy" and depending on the frequency is either short wave or microwave So far as is known diathermy has no proved ef

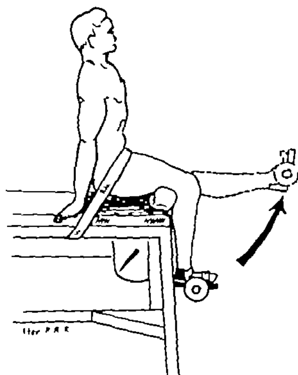


Fig 610 —Technique of progressive resistance exercise for developing strength of knee extensors

fect on tissues other than that resulting from increased temperature Because of the ability of high frequency electrical energy to penetrate tissues deep heating effects are obtainable in less time than with other methods of applying heat. It is therefore possible to obtain adequate heating in 20 minutes by the use of diathermy Most of this electrical energy is absorbed by the blood in the tissues and is an effective stimulus to circulation It is not generally accepted that diathermy has a specific beneficial effect on a formation of callus in fact, some evidence indicates that excessive heating by diathermy may possibly cause some osteoporosis or decalcification of bone by increasing circulation Because of the large amounts of energy which are delivered to the tissues it is especially important that there be normal sensation if diathermy is to be used as is necessary with all forms of heat application The use of diathermy over growing epiphyses is contraindicated The correct technique of application of diathermy is dependent on knowledge of its physics and training in methods of operation The technical details are beyond the scope of this discussion In the after-care of fractures the prolonged use of diathermy without exercise therapy is deprecated

Ultrasound

Currently the newest method for the application of heat involves the use of high-frequency vibratory energy in the form of ultrasound waves The vibrations are too rapid to be heard by the human ear (700 000–1 000 000 per second) Ultrasound generators now available are effective in producing local heat. This can be done in 5–10 minutes by direct application of the sound applicator to the skin through a proper coupling medium such as mineral oil or a water bath So far as is known, the fundamental effects of ultrasound application result from the increases in temperature produced when the mechanical energy is converted to heat in the body Although consideration of the physics involved shows that ultrasonic energy when applied to a limb may selectively increase bone temperature it has not yet been demonstrated that this is a desirable method of treatment for fractures and so it is not recommended for general use

MASSAGE

The beneficial effects of massage as part of the physical medicine prescription are dependent on the type of movement and the dosage In the early treatment of fractures superficial stroking may have a sedative effect with relief of pain and muscle spasm Deeper massage when permissible is a greater stimulus to circulation The greatest effect however is on the venous

return which is facilitated both reflexly and mechanically In view of this properly executed massage may lead to some decrease of swelling For all practical purposes, however massage is of benefit only in the most skilled hands and under expert guidance by the physician or surgeon Because of the danger from massage in inexpert hands and without proper medical supervision it is best to omit this aspect of the treatment if there is any doubt in the surgeon s mind.

EXERCISE

The essence of proper prescription of physical medicine in the after-care of fractures lies in the utilization of adequate exercise. Customarily exercise is divided into passive active and resistive exercise It should be emphasized at once that passive stretching to obtain motion in the early after-care of fractures is contraindicated The nearest approach to passive motion is that of truly relaxed active motions plus assistance The only practical means of obtaining motion and muscle strength is through properly supervised active exercise The prescription of such active exercise should include a stipulation of the limitations of range of motion so that the physical therapist may safely guide the patient. The prescription should also mention positioning of the parts and support of certain areas when indicated. The actual limitation of the extent of motion is largely dependent on the reaction of the patient Pain and muscle spasm produced by the exercise are signals that the range has been exceeded

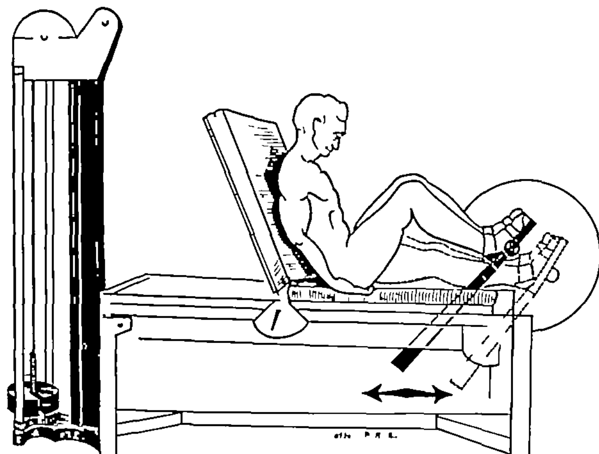


Fig. 611 —Technique of progressive resistance exercise for combined hip and knee extension

The physiological effects of active exercise are well known It is this type of exercise which is most effective in the hypertrophy of muscle fibers and coincident increase in power At the same time exercise increases both arterial and venous

circulation hence leading to decrease in swelling As an end result there is as desired greater muscle power increased range of motion and increased nutrition and circulation for the affected area

One exercise technique warrants special discussion—the progressive-resistance exercise When strong bone union has been secured in fractures particularly of weight bearing bones the individual may not be able to resume full activity because of weak musculature *A most effective means of* quickly developing muscle power is to apply near maximum resistance and low repetition exercises An excellent example of a valuable exercise is the knee-extension exercise used in cases of fractured femurs (Fig. 610) Applications have also been developed for hip back and leg musculature (Fig. 611) Special equipment is available for use in hospital departments but for the quadriceps an aluminum boot and weights may be supplied for home use For details of technique the reader is referred to other publications (see Bibliography)

CRUTCH WALKING

Many patients with fractures of the lower extremity require the use of crutches at some time during their convalescence It is accordingly essential that these patients be equipped with the proper size crutches and that they receive instructions in their proper use as indicated for the particular patient.

Selection of Crutches

Most patients have a single fracture or fractures of only one lower extremity and the choice of crutch presents no particular problems The crutch can be either a standard double upright underarm crutch or as may be preferred an adjustable underarm crutch (Fig 612 *A*) The crutch should be provided with a suction tip and very often with an underarm axillary pad For the patient having some lack of triceps power a short aluminum crutch may be used (Fig 612 C) The latter crutch may be used in place of a cane when the patient requires more stability than would be provided by a cane alone *It is also preferred* by patients who are required to use crutches for a long period of time There is a certain convenience in using this type of crutch since the patient is able to release his grasp from the handle while the crutch remains supported on the forearm Special arm and hand supports may be utilized in particular cases where there are *complications of arthritis* or muscular weakness but this type of problem is beyond the scope of this chapter

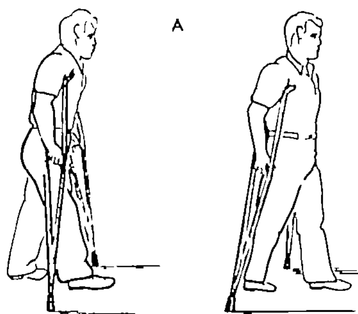
Measuring for Crutches

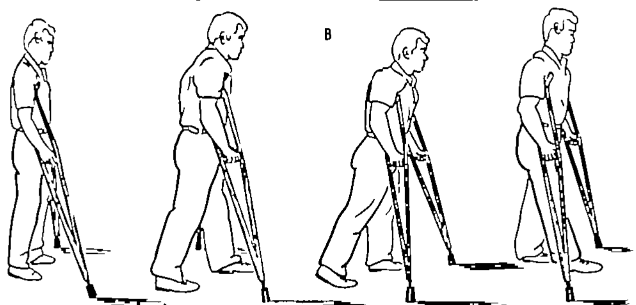
To measure a patient for crutches the height of the crutches or their length and the level of the hand piece are the points of consideration The length of the crutches is important, because if they are too long there will be pressure in the axilla and this may be against the radial nerve causing a crutch paralysis or radial nerve palsy If the crutches are too short improper stance will result. The hand level is important—it should be such that an angle of 30 of flexion is present at the elbow joint.

One method of measuring is to have the patient lie straight in bed and to measure from the anterior fold of the axilla to a point 6 inches from the level of the bottom of the foot—that is 6 inches out from the side of the level of the bottom of the foot. An alternative method is to measure from the anterior point of the axilla to the foot and add 2 inches *In many instances it is* best to utilize adjustable crutches so that the length and the level of the hand grasp are finally decided when the patient is up

Accessories

Rubber covers for the shoulder piece are helpful to prevent undue pressure and a large suction tip 1½ or 2 inches in length is also helpful The small round tips are not safe because they do not hold well at all angles with the ground.





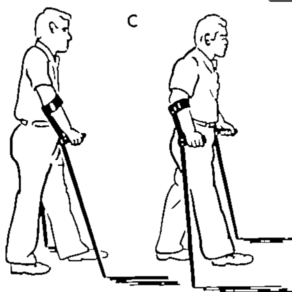


Fig. 612.—A three-point gait B four-point alternate gait C two-point alternate gait.

Three Point Crutch Gait

For patients with fractures of one lower extremity the usual gait prescribed is the three-point gait (Fig. 612 A) This gait is used to avoid full weight bearing on the affected extremity The crutch sequence is (1) both crutches and the weaker lower ex tremity then (2) the stronger lower ex tremity In this way the two crutches and weaker limb are placed simultaneously and then the stronger limb supporting the whole body weight, is advanced

Four Point Alternate Crutch Gait

This gait (Fig 612 B) is used for bi lateral involvement and is the most ele mentary gait. It is a safe gait because there are three points of support on the floor but it is slow because the weight must be constantly shifted.

The sequence is as follows (1) right crutch (2) left foot (3) left crutch and (4) right foot.

Two-Point Alternate Crutch Gait

For a patient who has mastered the four point alternate crutch gait the two-point alternate crutch gait (Fig. 612 C) may be taught, *since the latter increases speed* Actually it can be as fast as the walk of the average normal person This gait requires more balance control because only two points are supporting the body at one time

Crutch sequence (1) right crutch left foot simultaneously (2) left crutch and right foot simultaneously

ELECTRODIAGNOSIS

Whenever there is a suspicion of a nerve lesion, electrodiagnostic tests are of utmost importance It is often possible by these tests to differentiate between a torn tendon and a nerve injury This is particularly true in the case of a dislocated or a fractured shoulder where there may be diffi culty in regaining active abduction I trodiagnostic tests include direct mu stimulation for determination of elect excitability Quantitative aspects of tl tests include determination of resp to galvanic stimulation measuremen the chronaxy and in some instances complete strength-duration curve The for the classic reaction of degeneratio Erb is more qualitative than quantita

Another method of great importanc electromyography with an intramusc needle electrode in the questionable r cle Visual and audio records are produ using a cathode-ray oscilloscope and a l speaker If the physician observes dene tion potentials indicating fibrillatior muscle fibers which are denervatec nerve injury is undoubtedly present may of course pick up action potent representing motor-unit activity whick dicates that the nerve has not been c pletely severed or is not physiologic lacking in conduction. Progress of ne regeneration can be followed by both these electrical methods of quantitat

ELECTROTHERAPY

Normally innervated skeletal mu which has become weak or atrophied fr disuse or immobilization may be made contract by appropriate electrical stim tion The currents used for this purp have certain physical characteristics order to obtain optimum usefulness ' current must have sufficient intensity overcome the threshold of excitabil each individual impulse must have su cient duration to overcome the time fac of excitability and the wave form of individual impulse must have an abr rise so that the threshold is not raised the process of accommodation. Las there must be an adequate frequency individual impulse to produce a sustair smooth tetanic muscular contracti Every well-equipped hospital physical th apy department has a variety of comm cially available stimulators which can used for this purpose

Some generators are quite elaborate having mechanical means of surging the current on and off gradually others have a manual control by which the therapist can make and break the current From the point of view of comfort the individual impulse of short duration with high voltage and minimum amperage produces the least sensory stimulation or pain The current used for the greatest number of years is that produced by an induction coil or faradic current at present this current is less popular than the currents produced by various oscillating tube circuits A general rule to follow is to have the electrical stimulation produce an individual impulse usually of about a millisecond s duration The frequency should be between 50 and 200 per second and the intensity should be easily controlled by an appropriate potentiometer If the current is unidirectional, the cathode or negative pole is usually applied at the motor point of the muscle One of the most comfortable currents producing a strong contraction is similar to a static machine in that a high voltage discharge in a vacuum tube is produced and enters the muscle through glass and air spacing. Such a generator is produced by the Batrow Company

Although a number of stimulators are available their definite value in therapy is not well established with certain exceptions. It is generally accepted that a voluntary contraction is the most effective way of getting back power of normally innervated muscle However in some cases of prolonged immobilization a patient may seem to forget how to voluntarily contract a muscle and a few electrical stimulations of the muscle may help in muscle reeducation. This type of the use of electrotherapy seems to be the most logical from our present knowledge

In the presence of a nerve injury completely denervated muscles may also be made to contract by appropriate electrical currents Because denervated muscle has specific characteristics of electrical excitability the selection of currents must be in keeping with this excitability Intensities are in the same range as those for innervated muscle but the time characteristic of excitability is quite different Stimuli of longer duration must be used in keeping with the increased chronaxy or time threshold of excitability The average duration of a rectangular wave form stimulus for denervated muscle is 50 milliseconds The frequency of stimulation needed to produce the sustained contracture is also different and for denervated muscle the frequency need only be approximately 10 per second Therefore a current of adequate intensity with impulses of 50 milliseconds duration and with a frequency of 10 per second can be used satisfactorily to stimulate denervated muscle Again the current may be turned on mechanically slowly in a surge wave and similarly turned off by sharp make and break with a manual switch It has been shown that the atrophy of denervation cannot be prevented by electrical stimulation nor does this stimulation have an effect on the regeneration of the nerves Experimental work suggests that only stimulation at least twice a day every day for 5–10 minutes at a time per individual muscle and with maximum contraction has any physiological effect Consequently for practical purposes electrical stimulation of denervated muscle is in most instances confined to testing purposes

OCCUPATIONAL THERAPY

An important aspect of physical medicine treatment in the after-care of fractures includes the use of occupational therapy techniques This is of course free active exercise within the limits of pain and fatigue tolerance The particular advantage of occupational therapy as a means of providing active exercise is that the patient is engaged in an activity that produces some objective result either through arts or crafts or through other visual manifestation of his efforts In many patients this activity leads to relaxation and reduction of muscle spasm and it also provides an incentive for spontaneous par

ticipation in the activity Occupational therapy is especially helpful in injuries which cause disability in the upper extremities for recovery of manual dexterity and skill is particularly important and can rarely be achieved simply by specific exercises *In the earlier stages of after-care* occupational therapy is a logical correlate to physical therapy and in a hospital department the two types of procedures are usually combined For example the patient starts with whirlpool baths and massage and is then referred to occupational therapy for specific prescription of activities to improve range of motion and to increase skill dexterity and muscle strength. The occupational therapist must be told of positions to be avoided or of other needs for precaution (e.g. the presence of diminished sensation) lest damage be done by inadvertent application of mechanical or other forces to anesthetic areas

INSTRUCTION OF PATIENT IN HOME CARE

The importance of the active co-operation of the patient in securing a good end result has been stressed. It is rarely possible to provide enough supervised physical and occupational therapy to make sure that the patient has sufficient active use of the involved part to secure return of function It is therefore necessary to instruct the patient and instill in him the desire to improve results through his own efforts Accordingly it is good practice to teach the patient to use simple methods of heat application and in particular to encourage him to do exercises at home which he can repeat many times a day without any elaborate apparatus

In more difficult cases especially those that require the regaining of a particular skill, occupational therapy may provide a home program of activity which the patient may practice for many hours on his own with only the necessary checks of progress and supervision of exercises or other therapy activities whenever seen by the doctor Years of experience have shown that in perhaps the majority of uncomplicated fractures adequate advice from the surgeon regarding a home exercise program including if indicated application of heat of a simpler type may be sufficient *to secure good return of function.* Individuals vary greatly however in their ability to learn how to exercise properly and it may be a time-consuming procedure to supervise patients in a home exercise program to make sure that it is done effectively For some individuals a few supervised treatment sessions in physical therapy may be of immeasurable value in teaching them how to carry out an effective home program

PROBLEMS IN REHABILITATION

Physical medicine procedures adequately applied, are probably successful in rehabilitating most patients with uncomplicated fractures However a sizable number of patients have complications and more serious injuries particularly of weight bearing joints which require procedures beyond those available in the usual physical and occupational therapy departments. These patients usually present long-term problems of after-care because of the severe trauma and the long period of disability and other factors become important in the management of these cases.

Prolonged periods of immobilization in the hospital or a home may lead to considerable psychological, as well as physiological disability simply from inactivity and boredom Some of the physiological effects are of course to a large extent obviated by instructing and interesting the patient in an active exercise program for the uninvolved muscles of the body since such exercises tend to maintain a more normal metabolism Other adverse effects of immobilization and inactivity may also be in part prevented by giving him occupational therapy to provide an interest in an activity within his reach while immobilized. In addition it is important to

consider the objectives and problems of economic rehabilitation and return to employment

The importance of an over all approach to rehabilitation of the seriously injured patient cannot be overemphasized This has been manifested again and again by those caring for industrial cases It is generally believed—and there are certainly figures to bear out the beliefs—that if the disability is unnecessarily prolonged for months or years the chances for successful rehabilitation even with the best facilities, are greatly hampered by delay in making the facilities available to the patient

It is of course obvious that no amount of expert rehabilitation service can make up for a lack of proper reduction and good anatomical realignment of all functioning parts.

A review of the fracture patients referred to the Bay State Medical Rehabilitation Clinic at the Massachusetts General Hospital in its first 3 year period showed that about 30 per cent of the new patients each year were referred for treatment of fractures About 25 per cent of these had upper extremity fractures usually with such complications as severe limitation of adjacent joints or other tendon or nerve injuries The largest percentage of patients (75 per cent) had involvement of the weight-bearing joints of the lower extremities which incapacitated them for months or years.

The procedures usually included under this stage of rehabilitation should begin with an evaluation of factors of motivation in the patient It should be emphasized, however that proper motivation cannot be expected to be automatic since it is dependent on orientation as to what end result is to be expected in the particular case Realistic goals must be established in the event of permanent residual disability and provision made for guidance and necessary training in the learning of new skills In some cases of course lack of function can be explained not on any organic disability or on lack of motivation but on a deep-seated emotional reaction to the disability This is usually treated only with guidance or with the active therapeutic participation of a psychiatrist In this series at the Rehabilitation Clinic there were no patients with frank psychiatric disorders related to their trauma

Experience has shown however that an all inclusive rehabilitation program may be of definite value in the most difficult cases Such a program may include graduated physical activity under supervision and often group activities correlated with occupational therapy procedures to improve work tolerance and interest in productive activity Social service workers are helpful in orienting the patient to the program and going into economic problems and social problems related to his injury and in securing help for him in matters such as compensation and transportation and in explaining his disability to other members of the family In a large general hospital it may be possible to utilize the hospital industries in a therapeutic manner For example patients can often be stimulated to work in the hospital carpentry shop or plumbing shop in the dietetic department in bookkeeping accounting or printing or in the almost endless occupations that are part of any hospital administration and are similar to those in which the patient was previously employed or in which he may seek to be employed in the future In a sheltered, protective environment associated with the rehabilitation clinic the patient may be encouraged to increase his work activity and to develop the self assurance so important in rehabilitation The ability to work in a group with other people is an aspect of treatment not to be neglected in a complicated case

The rehabilitation of patients with permanent disabilities includes proper vocational testing guidance and when indicated retraining in another type of employment. Retraining can be achieved through knowledge and understanding of the agencies available for this purpose and by work with these agencies in provid

ing an evaluation of the particular patient and his physical and intellectual capabilities and interests The United States Government has provided through the departments of vocational rehabilitation in all states facilities for this type of counselling and for the necessary vocational training It is urged that the doctor caring for seriously injured patients be aware of all the available rehabilitation procedures and refer the patients to appropriate agencies for necessary occupational and physical therapy

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